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ENVIRONMENTAL ASSESSMENT OF COAL CLEANING PROCESSES: FINAL REPORT

by

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16. ABSTRACT The report summarizes a 3-year evaluation of coal cleaning processes. It discusses: physical coal cleaning (PCC) technology; the potential role of PCC in producing coals for compliance with SO2 emission regulations; pollution controls for PCC plants; assessment criteria and test methods for environmental testing at PCC plants; and baseline environmental tests at the Homer City coal preparation plant. Physical coal preparation is used extensively to remove mineral matter from boiler fuels. Major operations for coal preparation are: crushing and sizing, coal cleaning, dewatering and drying, waste disposal, and pollution control. PCC can also remove pyritic sulfur and increase the supply of compliance coals. PCC plants generate air and water pollutants, and solid wastes. Fugitive dust is generally controlled by equipment enclosures, dust collection systems, wetting, or chemical dust suppressants. Particulates from thermal dryers are controlled by scrubbers. The most common water pollution controls are sedimentation and neutralization. Solid wastes are disposed of in landfills or sedimentation ponds. Pollutants directly associated with PCC are primarily inorganic. In assessing potential hazards from these pollutants and in selecting sites for environmental tests, it is important to consider the: soil acid neutralization potential, coal pyritic sulfur content, and PCC process used.

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Coal Preparation		Stationary Sources	08I
Desulfurization		Environmental Assessment	07A,07D
Dust			11G
Processing		Physical Coal Cleaning	13H
Leakage		Fugitive Dust Particulate	14G

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FOREWORD

Many elements and chemical compounds are known to be toxic to man and other biological species. Our knowledge concerning the levels and conditions under which these substances are toxic is extremely limited, however. Little is known concerning the emission of these pollutants from industrial processes and the mechanism by which they are transported, transformed, dispersed, or accumulated in our environment.

Portions of the Federal Clean Air Act, the Resource Conservation Recovery Act, and the Federal Water Pollution Control Act require the U.S. Environmental Protection Agency (EPA) to identify and regulate hazardous or toxic substances which result from man's industrial activities. Industrial pollutants are often identified only after harmful health or ecological effects are noted. Remedial actions are costly, the damage to human and other biological populations is often irreversible and the persistence of some environmental contaminants may endanger future populations.

EPA's Office of Research and Development (ORD) is responsible for health and ecological research concerning the transportation and fate of pollutants, and the development of technologies for controlling industrial pollutants. The Industrial Environmental Research Laboratory, an ORD organization, is responsible for development of pollution control technology and conducts a large environmental assessment program. The primary objectives of this program are:

- The development of information on the quantities of toxic pollutants emitted from various industrial processes--information needed to prioritize health and ecological research efforts.
- The identification of industrial pollutant emissions which pose a clearly evident health or ecological risk and which should be regulated.
- The evaluation and development of technologies for controlling pollution from these toxic substances.

The Coal Cleaning Environmental Assessment program has as its specific objectives the evaluation of environmental control problems and solutions which are unique to coal preparation, storage, and transportation. In this final review of this major study, significant contributions are reported in the areas of the status of physical coal cleaning technology, the potential roles of coal cleaning in achieving compliance with sulfur dioxide regulations, and the necessary pollution control technologies for coal cleaning processes. Additional contributions are a detailed sampling and analysis procedure to document the environmental acceptability and benefits of coal cleaning and a number of computer models and information systems useful in designing or selecting state-of-the-art coal cleaning technologies from among technical, environmental, and economic options.

ABSTRACT

This U.S. Environmental Protection Agency/Battelle's Columbus Laboratories program has established a strong base of engineering, ecological, pollution control, and cost data which can be used to determine which coal cleaning processes are most acceptable from the technological, environmental, and economic viewpoints. This report represents a final summary of results of this major, three-year environmental assessment of coal cleaning processes.

Beyond the introduction and summary, the report includes chapters on (1) the status of coal cleaning technology, (2) the potential role of coal cleaning in SO_2 regulatory compliance, (3) an overview of pollution controls, (4) description and results of sampling and analysis programs, and (5) a description of models and information systems developed for the project.

This report was submitted by Battelle's Columbus Laboratories in support of work performed under U.S. Environmental Protection Agency Contract No. 68-02-2163 for an Environmental Assessment of Coal Cleaning Processes. The contract period was July 2, 1976, to September 1, 1979.

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INTRODUCTION AND SUMMARY

The U.S. EPA/Battelle coal cleaning project has established a strong base of engineering, ecological, pollution control, and cost data, which can be used to determine which coal cleaning processes are most acceptable from the technological, environmental, and economic viewpoints. The data can be used for the performance of trade-off studies encompassing coal cleaning and other clean fuel strategies, for identification of optimum process configurations and pollution control equipment, and for determination of the most environmentally acceptable coal cleaning processes.

Physical coal cleaning processes have been used for many years to upgrade coal quality. The upgrading of coal involves removal of sulfur compounds and other mineral constituents from coals for use in boilers and for metallurgical uses. Recently, there has been interest in the use of physical coal cleaning to reduce other potential pollutants (i.e., trace metals in fly ash) and to enhance economic benefits (i.e., through reduced transportation costs and reduced boiler maintenance).

Physical coal cleaning is a fully developed technology whose commercial application is currently not expanding at the rate one might expect in light of the potential economic and environmental benefits. Some of the factors which have slowed its rate of commercial application are:

- Coal users may have to become involved in the mining business in order to produce physically cleaned coal, since coal cleaning is most convenient near the mine.
- Since coal cleaning is most convenient near the mine, user involvement may be required in some instances to produce physically cleaned coal.
- Coal users are unfamiliar with many of the benefits derivable from the use of cleaned coal.
- There is insufficient information available on the washability of U.S. coal reserves.

- There is uncertainty about the future of environmental pollution control regulations associated with coal handling and use.

The benefits to the owners of coal cleaning plants as well as the benefits to the nation need to be more clearly defined and widely publicized if these deterrents to development are to be overcome.

Potential markets for physically cleaned coals include (1) utility boilers, (2) industrial and commercial boilers, and (3) systems converting coals to gaseous or liquid fuels. As new stationary source performance standards (NSSPS) for SO_2 become more stringent, physically cleaned coals may become useful in utility boilers primarily as a complementary control technique along with flue gas desulfurization (FGD). Industrial and commercial boilers, on the other hand, may begin to switch from oil or gas to physically cleaned coals, especially when gas and oil become unavailable or prohibitively expensive. Physically cleaned coals are likely to find an application in connection with coal conversion processes, although this market may not develop until some years in the future.

As part of this program, Battelle completed a study on the potential of physical coal cleaning as a control technique for SO_2 emission from utility boilers. This work showed that an estimated total of 62.4 billion short tons of recoverable coal reserves can be burned without cleaning or can be physically cleaned to comply with the then-existing New Source Performance Standards (NSPS) for SO_2 emissions. Slightly more than half of the above quantity of coal is sufficiently low in sulfur to be burned without cleaning and still be in compliance. With the lower NSSPS limits for SO_2, however, the use of physically cleaned coals will need to be combined with FGD in most situations in order to meet the reduced emission limits.

Analysis of the cost of physically cleaning coals generated the following estimates of costs per ton of coal cleaned:

(1) Capital charges - \$0.44 to \$2.79

(2) Operation and maintenance - \$0.75 to \$5.00.

The Btu value of coal lost during physical cleaning was estimated to be \$0.53 to \$2.00 per ton of cleaned coal for cleaning plants processing coals worth \$1.00 to \$25.00 per ton with 60 to 90 percent weight yield. The energy value of the coal lost to refuse is much more important than the power required to operate the cleaning processes and may amount to 10 to 15 percent or more of the Btu's available in the raw coal.

One of the main purposes of coal preparation is to reduce the potential pollutants in raw coal prior to its utilization, so that the emissions resulting from coal usage can be reduced. However, the waste materials generated by coal preparation can themselves be sources of pollution.

In another portion of this study, Battelle described and evaluated the various pollution control technologies and their costs associated with coal cleaning plants and their associated facilities. Equipment, techniques, and costs are discussed for control of (1) particulates and gases in gaseous effluents, and (2) suspended and dissolved materials in water and slurry effluents. Efficiencies of various air pollution control devices are examined. Techniques and costs for coal cleaning refuse disposal are described which reduce or eliminate the problems, i.e., fugitive dust, refuse pile fires, erosion, and leachate generation. Methods frequently used to dispose of refuse physically are compared and reclamation procedures and their costs are reviewed.

In another phase of the U.S. EPA/Battelle assessment of coal cleaning processes, a field sampling and analysis program was designed to identify the combinations of coal cleaning processes and environmental conditions that are the most effective in reducing the total impact of coal use on the environment. This will be accomplished through the characterization of process and effluent streams from a variety of coal cleaning facilities and their associated coal transportation, storage, and refuse disposal areas. These data will be used to support the overall environmental assessment of coal cleaning plants, as well as to support the evaluation and optimization of pollution control equipment and waste management techniques.

The results of the field testing program when completed will be of direct use to cooperating facility owners and of indirect use to the entire coal preparation industry. Cooperating facility owners will be able to use the program's analytical results for compliance with regulations in the Resource Conservation and Recovery Act and the National Pollutant Discharge Elimination System. Benefits to the coal preparation industry should eventually include reduced costs for pollution control, elimination of unnecessary pollutant monitoring and reporting requirements, and improved pollution control technology.

Preliminary developmental work was conducted on computer programs for optimization of coal cleaning plant configurations, control technology, and emission control systems. The optimization process emphasizes maximum removal of sulfur and other undesirable elements, while minimizing Btu loss and cleaning costs. Preliminary work was performed evaluating several different programs for optimization at different levels including (1) performance estimation of coal cleaning equipment; (2) cleaning equipment plus emission control equipment; and (3) the entire coal processing system (including transportation, handling, and storage; physical coal cleaning with control technology; chemical coal cleaning; and end-use control techniques).

At the conclusion of this portion of the EPA Coal Cleaning Environmental Assessment program, there is strong evidence to support the expansion of physical coal cleaning as a method for producing an environmentally and economically acceptable energy source for utility and industrial needs.

COAL CLEANING TECHNOLOGY STATUS*

Commercially available physical coal cleaning (PCC) processes** have been used worldwide for many years to improve coal quality. Relatively simple systems are used to remove ash-forming constituents from coals supplied for boiler fuels. More elaborate systems are used to remove ash-forming constituents and pyritic sulfur from metallurgical coals. In the mid-1960's the U.S. Environmental Protection Agency (EPA) initiated programs to develop information on the usefulness of physical coal cleaning for reducing sulfur oxide emissions from utility boilers. It was soon determined that such information was not available. As a result, the U.S. EPA, working with the U.S. Bureau of Mines and others, conducted numerous projects aimed at (1) evaluating the degree to which steam coals of the U.S. could be desulfurized using physical coal cleaning techniques, (2) determining the effectiveness of commercially available coal preparation equipment for sulfur removal, and (3) evaluating processes that could utilize the coal associated with the rejected mineral matter and thereby increase the degree to which coal could be economically cleaned with physical methods. This activity, along with the work of others, has led to a growing appreciation of the possibilities for using physical coal cleaning, alone or in combination with other methods, to minimize sulfur oxides pollution. In addition, there is interest in using PCC for minimizing other potential pollutants (e.g., fly ash and trace metals) and for realizing other economic benefits such as reduced transportation costs and reduced boiler maintenance.

While physical coal cleaning systems are commercially available and have been in use for many years for traditional applications (e.g., rough cleaning for removal of ash and mining residues from utility coals or for removal of ash and pyritic sulfur from well characterized metallurgical coals), only one system has been designed and operated specifically to reduce the sulfur content in coal burned by a utility. This is the multistream coal cleaning system (MCCS) for the Homer City electric power generating station jointly owned by Pennsylvania Electric Company and New York State Electric and Gas Corporation. The ultimate capacity of this coal cleaning facility will be 1200 tons per hour of raw coal.

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* Content supported by Battelle report, "Environmental Assessment of Coal Cleaning Processes: Technology Overview".(1)

** Physical coal cleaning processes are those that remove ash-forming minerals and pyritic sulfur from coal without chemical modification or destruction of the coal or other mineral matter.

There has been considerable testing of U.S. coals to estimate what sulfur and ash reductions are economically achievable. The U.S. Bureau of Mines conducted washability studies of 455 raw coal channel samples from six major coal-producing regions.(2) These samples were obtained from mines which provide more than 70 percent of the annual U.S. utility coal production. The results of these studies indicate that substantial reductions in sulfur and ash content can be attained for numerous coals. They also indicate, however, that maximizing the effectiveness of PCC will require modified approaches to accommodate variations in the properties of U.S. coals as they occur in different regions, different coal beds within regions, and within individual coal beds.

Table 1 shows the differences in results obtained when different coals are given similar processing. These results were obtained by Battelle for a simulated process equivalent to a physical separation at a specific gravity of 1.6 after crushing to a miximum size of 3/8 inch. As will be noted, sulfur removal levels are high except for Southern Appalachia and Alabama regions. The variations shown are obviously due to the variation in coal characteristics and indicate the need to optimize the cleaning process used in terms of the coal properties.

Estimating the degree to which PCC is applicable to boiler fuel production is further complicated by uncertainties regarding the levels of future pollution control standards. Physical coal cleaning is by far the cheapest method per unit of sulfur removal for "cleanable" coals, and for small boilers it may be the only economically feasible route to control. However, precise control of product sulfur content at a particular level on a continuous basis is not presently possible due to sulfur variability within a coal seam.

In summary, PCC technology is an established technology which is now being adopted and applied as a pollution control method. While a considerable

TABLE 1. AVERAGE SIMULATED CLEANING PERFORMANCE BY REGION(1)

(Float Product at 1.6 Specific Gravity for 3/8 Top Size)

Region	Btu Recovery, percent	Mass Recovery, percent	Percent Sulfur in Raw Coal	Percent Sulfur in Cleaned Coal	Percent Reduction in Sulfur	lb $SO_2/10^6$ Btu in Raw Coal	lb $SO_2/10^6$ Btu in Cleaned Coal	Percent Reduction in lb $SO_2/10^6$ Btu	Percent Ash in Raw Coal	Percent Ash in Cleaned Coal	Percent Ash Reduction
1. (N. Appalachia)	96.0	93.4	2.79	1.93	30.8	4.25	2.86	32.7	11.87	7.32	38.3
2. (S. Appalachia)	97.0	95.0	1.04	0.90	13.5	1.51	1.28	15.2	8.78	5.07	42.3
3. (Alabama)	96.5	94.2	1.28	1.13	11.7	1.90	1.64	13.7	10.82	6.61	38.9
4. (E. Midwest)	96.4	93.5	3.89	2.80	28.0	6.32	4.41	30.2	13.51	8.04	40.5
5. (W. Midwest)	95.2	90.3	4.42	3.23	26.9	7.23	5.01	30.7	15.54	7.96	48.8
6. (Western)	97.9	97.3	0.65	0.45	30.8	1.09	0.75	31.2	8.07	5.84	27.6
7. (Entire USA)	97.1	95.3	1.90	1.35	28.9	3.07	2.14	30.3	10.27	6.57	36.0

amount of information relative to this usage has been accumulated, there is still much to learn.

PHYSICAL COAL CLEANING SYSTEMS

Physical coal cleaning (PCC) systems that might be employed today range in complexity from simple systems for removing coarse refuse to highly sophisticated systems designed for maximum removal of sulfur and ash from a specific coal supply. The central components of PCC systems are the separation processes that divide the product stream from the refuse fraction. Three operations are performed: coal pretreatment, coal cleaning, and product conditioning. Other auxiliary processes are employed for coal handling, water treatment, and solid waste disposal. All operations employ a variety of processes with different potentials for discharging pollutants. Figure 1 schematically displays the processes and operations which are incorporated in PCC systems. The indicated sizes may vary in practice and are shown only as typical size ranges for coarse, fine, and ultrafine coal cleaning circuits.

Cleaning effectiveness is a function of the effectiveness of a PCC system in removing impurities (inorganic sulfur compounds and other mineral matter), and effectiveness in recovering high percentages of the Btu's available in the raw coal. Unfortunately, these two objectives are often difficult to achieve simultaneously and can be mutually exclusive. Three levels of cleaning effectiveness which involve a compromise between ash and sulfur removal and Btu recovery are currently practiced:

(1) Minimum cleaning effectiveness involves crushing and sizing of raw coal, cleaning the coarse fraction (3 x 3/8 inch) in jigs or dense-medium vessels, and then combining or not combining the uncleaned fine and ultrafine fractions (3/8 inch x 0*) with the cleaned coarse fraction. With this level, it is possible to obtain either a high quality coal product or a high Btu recovery, but not both. A high quality coal product may be obtained by use of a low specific gravity of separation (near 1.3) for the coarse fraction and by not combining it with the

---

* 0 denotes that no ultrafines have been removed.

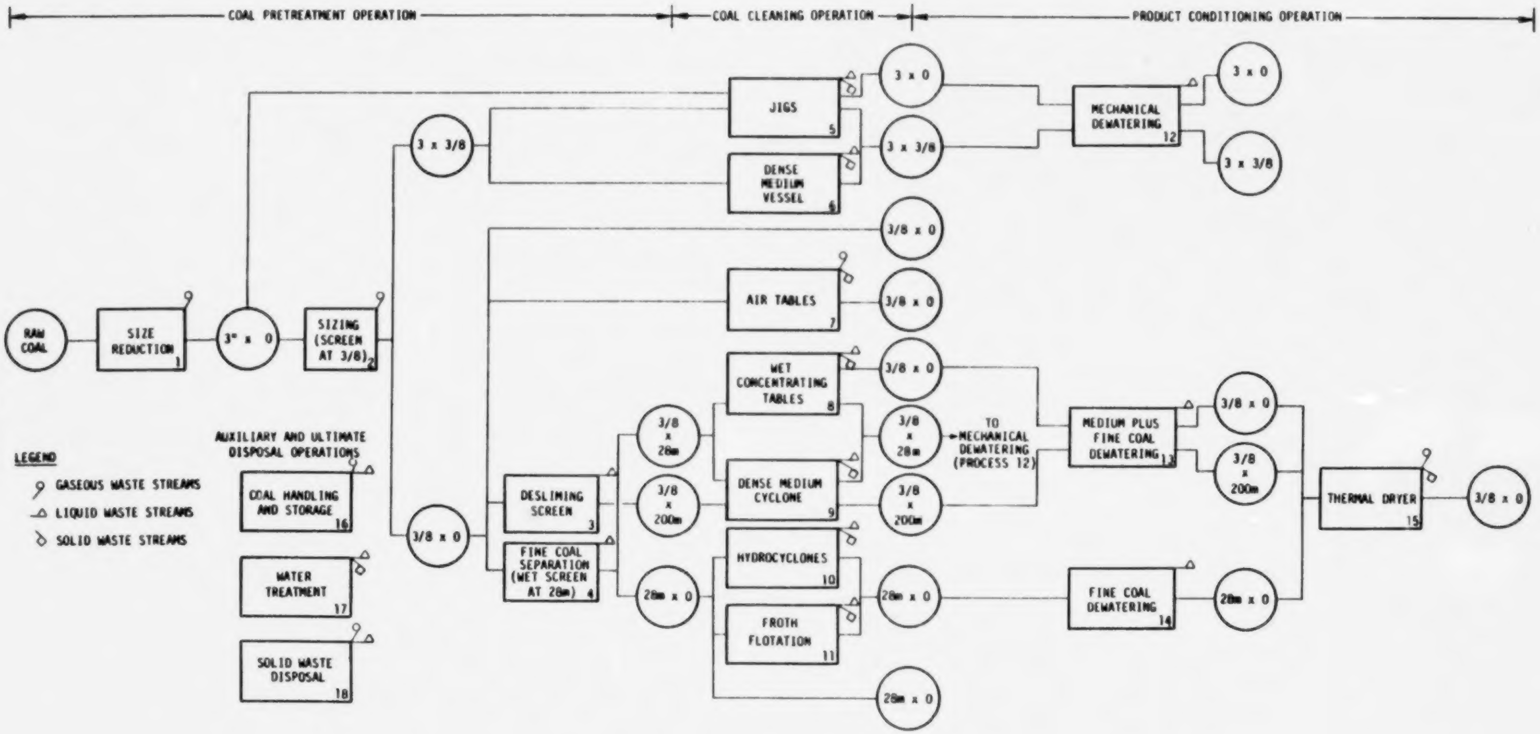
COAL PRETREATMENT OPERATION
COAL CLEANING OPERATION
PRODUCT CONDITIONING OPERATION
RAW COAL
SIZE REDUCTION 1
3" x 0
SIZING (SCREEN AT 3/8) 2
3 x 3/8
3/8 x 0
JIGS 5
DENSE MEDIUM VESSEL 6
AIR TABLES 7
WET CONCENTRATING TABLES 8
DENSE MEDIUM CYCLONE 9
HYDROCYCLONES 10
FROTH FLOTATION 11
DESLIMING SCREEN 3
FINE COAL SEPARATION (WET SCREEN AT 28m) 4
3/8 x 28m
3/8 x 200m
28m x 0
3 x 0
3 x 3/8
3/8 x 0
3/8 x 0
3/8 x 0
3/8 x 28m
3/8 x 200m
28m x 0
28m x 0
TO MECHANICAL DEWATERING (PROCESS 12)
MECHANICAL DEWATERING 12
3 x 0
3 x 3/8
MEDIUM PLUS FINE COAL DEWATERING 13
FINE COAL DEWATERING 14
3/8 x 0
3/8 x 200m
28m x 0
THERMAL DRYER 15
3/8 x 0
AUXILIARY AND ULTIMATE DISPOSAL OPERATIONS
COAL HANDLING AND STORAGE 16
WATER TREATMENT 17
SOLID WASTE DISPOSAL 18
LEGEND
GASEOUS WASTE STREAMS
LIQUID WASTE STREAMS
SOLID WASTE STREAMS

FIGURE 1. PROCESS FOR PHYSICAL COAL CLEANING SYSTEMS

uncleaned fine and ultrafine fractions. A high Btu recovery may be obtained by use of a high specific gravity of separation (say 1.8) for the coarse fraction and by combining it with the uncleaned fine and ultrafine fractions.

(2) For the intermediate level of cleaning effectiveness, the coarse fraction is cleaned as in Level 1, and the combined fine and ultrafine fraction is cleaned with air tables, wet concentrating tables, or dense medium cyclones. Where dense medium cyclones are used, the 3/8 inch x 0 feed may be passed over desliming screens which yield a 3/8 inch x 200 mesh (M) material, which is fed to the dense medium cyclones.

(3) Maximum effectiveness in cleaning is obtained by cleaning the coarse fraction as in Level 1, splitting the 3/8 inch x 0 fraction into two fractions (e.g., 3/8 x 28 M and 28 M x 0), and cleaning the two fractions separately with equipment designed for maximum removal of sulfur and ash from fine and ultrafine size coals. The 3/8 inch x 28 M fraction is cleaned with wet concentrating tables or dense-medium cyclones. The 28 M x 0 fraction is cleaned using either hydrocyclones or froth flotation. PCC plants which incorporate processing of the 28 M x 0 fraction tend to employ thermal drying.

Table 2 illustrates eight basic systems that may be employed.

Coal Pretreatment Processes

Coal pretreatment processes are employed to generate feed streams with liberated impurities and particle size distributions that have been shown to be most effective for processing in the available coal cleaning processes. Raw coal is crushed to a top size of about 3 inches and screened to provide a coarse stream and a fine to ultrafine stream. The latter is either sold, processed directly, or further divided into fine and ultrafine size fractions for wet cleaning. The initial screening of crushed raw coal may be either wet or dry. Dry screening is used if air tables are to be used for coal cleaning. Wet screening is used where fine and ultrafine size streams are processed by wet cleaning processes.

TABLE 2. PHYSICAL COAL CLEANING PLANT TYPES*

System	Level of Cleaning Effectiveness	Coal Size and Process Coarse, 3" x 3/8"	Fine, 3/8" x 28M	Ultrafine 28M x 0
1	Minimum	CS+J or DMV	----------None---------	
2	Intermediate	CS+J or DMV	-----------AT----------	
3	Intermediate	CS+J or DMV	-----------WT----------	
4	Intermediate	CS+J or DMV	----------DMC----------	
5	Maximum	CS+J or DMV	WT	HC+TD
6	Maximum	CS+J or DMV	WT	F+TD
7	Maximum	CS+J or DMV	DMC	HC+TD
8	Maximum	CS+J or DMV	DMC	F+TD

Legend:

CS	Crushing and sizing
J	Jigs
DMV	Dense medium vessels
AT	Air tables
WT	Wet concentrating tables
DMC	Dense medium cyclones
HC	Hydrocyclones
TD	Thermal dryers
F	Froth flotation units

Note: All wet separation processes will have associated dewatering processes as shown in Figure 1.

* The eight types of coal cleaning plants listed are representative, but many other types exist or may be constructed. For example, in some cases jigs have been used for 3" x 0 coal instead of 3" x 3/8" coal at the minimum cleaning effectiveness levels. The raw coal may be crushed to a finer top size than 3" to maximize impurity liberation. At the maximum cleaning effectiveness level, hydrocyclones and froth flotation units may be used in combination for treatment of fine coal.

Coal Cleaning Processes

A number of approaches have been studied for non-destructive separations of coal from unwanted, associated mineral matter. These include methods based on specific gravity differences, surface properties, and responses to electrical fields or magnetic forces. Almost all methods with demonstrated commercial potential are based on specific gravity differences between the coal and other mineral matter. The only exception is froth flotation where differences in surface properties of coal allow it to be removed from aqueous suspensions of coal and inert minerals with air and organic flotation reagents.

The specific gravities of the principal coal constituents are: organic constituents--1.2 to 1.7, non-combustible ash (clay, shale, sandstone, etc.)--2.0 to 2.6, and pyrite--4.9 to 5.0. With differences of this magnitude, methods that separate fractions by specific gravity can be very effective where the components can be isolated from each other in reasonably pure form. Unfortunately, some impurities, pyritic sulfur in particular, are often present in very small, highly disseminated forms that require extensive size reduction to separate them from the coal. For very fine materials, the effectiveness of separation based on specific gravity decreases because of immobility of particles, particle-to-particle attractions, etc. Hence, froth flotation is finding increased application and other methods for fine coal cleaning are being studied.

Some historical trends, including the growth of froth flotation usage, are illustrated in Table 3. Pneumatic methods, because of ineffectiveness and problems associated with dust, moisture content, and size of equipment, have declined in use from 14 percent in 1942 to 4 percent in 1972.

Product Conditioning Processes

The product conditioning processes are primarily for removal of excess water. The processes employed vary with the size of coal being processed. For coarse coal, simple mechanical dewatering which involves the use of natural drainage from perforated bucket elevators or dewatering screens is employed. For finer coal, the surface area is much larger and the amount of

TABLE 3. PROCESSES EMPLOYED FOR PHYSICAL CLEANING OF COAL (Percentage of Clean Coal Produced, Year)(3)

Process	1942	1952	1962	1972
Jigs	47.0	42.8	50.2	43.6
Dense Medium Processes (Dense Medium Vessels and Cyclones)	8.8	13.8	25.3	31.4
Wet Concentrating Tables	2.2	1.6	11.7	13.7
Froth Flotation	-	-	1.5	4.4
Pneumatic (Air Tables, etc.)	14.2	8.2	6.9	4.0
Other (Classifiers and Launders)	20.5	13.7	4.3	2.9

moisture retained per unit of surface area is also larger. Tight packing and capillary action tends to hold water in void spaces. Hence, finer coals (less than 1/4 inch) require something more effective than natural drainage.

For coals which contain both fine and ultrafine fractions, e.g., 3/8 inch x 0 or 3/8 inch x 200 M, a sieve bend combined with a centrifuge for additional water removal may be used. For fractions made up exclusively of ultrafine materials (e.g., 28 M x 0), vacuum filtration is required. Fine and ultrafine materials are thermally dried.

ENERGY EFFICIENCY

The overall energy efficiency of PCC is influenced by the energy required to operate the process and by the energy value of the coal lost with the refuse. Power consumption by a PCC facility would be the equivalent to something less than 1 percent of the Btu input to the process. Btu's lost with the refuse usually are by far the more important of the two and might amount to as much as 5 to 15 percent in practice. There has been a tendency to consider Btu's in the waste material as equal in value to Btu's in the coal. This is misleading in that much of the carbonaceous matter which is rejected is low-grade material. Further, being in association with other unwanted minerals, it is of limited value for high efficiency combustion processes. The removal of such constituents, which is the primary purpose of physical coal cleaning, provides monetary benefits to operators of coal-fired boilers in terms of lower costs for coal transportation and handling, ash disposal, coal pulverizing, and boiler maintenance. Other cost benefits result from increases in boiler capacity factor and availability. Normally, the monetary value of the Btu's associated with the unwanted coal constituents is charged as a cost of coal cleaning, but, unless credits for the monetary benefits of using cleaned coal are also considered, the true cost (or value) of coal cleaning would not be properly assessed.

It is also important to appreciate that while the loss of coal in PCC refuse is a significant economic factor, the losses are not large when compared to those associated with other possible techniques for sulfur control. For example, flue gas desulfurization (FGD) systems consume energy in amounts equal to 3 to 10 percent of the fuel input to the boiler.(4) Technologies being developed to produce low-sulfur gaseous or liquid fuels from coal may attain efficiencies of 75 to 80 percent, but gasification or liquefaction technologies that can be used today are more likely to have efficiencies of 60 to 70 percent.

COSTS

Evaluation of the economics of PCC requires consideration of both costs and benefits which are highly specific to individual coal supply/coal user combinations. Further, some of the most important factors are difficult to quantify, e.g., the value of improved boiler operability and efficiency which may result from lower throughput of inert mineral matter and sulfur. Also, where PCC is being assessed as an approach to control of sulfur oxide pollution, it must be compared with available alternatives including flue gas desulfurization (FGD), the use of naturally occurring low-sulfur coals, and the use of PCC in combination with FGD. Finally, the economic factors can be assessed from several perspectives, e.g., that of a coal producer evaluating the return on investment that might be realized by selling cleaned coal or that of a coal user evaluating what might be saved using physically cleaned coal. All of these factors combine to make generalization relative to costs difficult. However, one recent study(5) demonstrates a definite economic advantage for PCC combined with FGD for SO_2 emission control, as compared to the exclusive use of FGD. Other data which have been accumulated have made it increasingly apparent that PCC can be very attractive economically in many situations, and it can ease the problems in meeting environmental objectives. Some of the findings considered most significant are presented in this section.

Physical Coal Cleaning Costs

For simplicity, only those costs which would be incurred by the operator of a PCC plant are considered here. No attempt is made to estimate the incentives for selling ROM coal, as opposed to physically cleaned coal, or the probable selling price of physically cleaned coal. Also, it should be noted that the overall cost of coal preparation may be expressed in units such as \$/ton of clean coal, \$/ton of raw coal, $\$/10^6$ Btu, or \$/lb of sulfur removed. In this report, costs are stated in several ways in an attempt to prevent confusion associated with the use of different terms.

The total cost of PCC includes three main elements, i.e., capital charges, operating and maintenance (O&M) costs, and the costs of the Btu's lost when combustible matter is rejected in the refuse stream from PCC processes.

Capital Charges

Annualized capital charges depend on three factors, i.e., capital investment, estimated useful life of the plant, and the interest or discount rate.

The capital investment required for a PCC plant is heavily dependent upon its size and complexity. With new plants being designed to achieve economy of scale, the complexity is probably the dominant cost-related factor for modern plants. Complexity is in turn dependent upon the cleanability of the coal and product requirements. The complexity-cost relationship can be illustrated by considering a range of costs* which have been reported. For a simple jig plant processing a 6-inch x 0 coal with the 48 M x 0 fraction processed in hydrocyclones to produce a 48 x 120 M clean coal fraction, the cost was \$6,600(6) per ton/hour of feed capacity. For the multistream coal cleaning plant at Homer City, Pennsylvania, which has been built to control emissions from a power plant, the reported cost was \$42,000 per ton/hour of capacity.(7)

Capital investment costs are converted to fixed annual charges on capital by using appropriate estimates for the useful life, L, of the facility (in years) and the interest or discount rate, i (annual percentage). The values of L and i determine the capital recovery factor (CRF) which is multiplied times the capital investment cost to obtain the fixed annual charges on capital. These charges allow for amortization of the capital investment and the time value of the money invested over the useful life of the physical asset. The approximate PCC capital investment cost range of \$6,600 to \$42,000 per ton/hour of capacity can be converted to a range for charges on capital as follows. With a plant useful life of 15 years and a discount rate of 18 percent**, the capital recovery factor (CFR) is 0.19640, which yields a range for fixed annual charges on capital of approximately \$1,296 to \$8,249 per ton/hour of capacity. With a plant capacity of 1000 tons/hour and a plant utilization of 42 percent, or 3690 hours/year, the range for charges on capital is approximately \$0.35 to \$2.24/ton of feed coal or \$0.44 to \$2.79/ton of clean coal if the weight yield is 0.8.***

Operating and Maintenance Cost

O&M costs for PCC typically include raw materials and supplies, utilities, labor, and overhead. Other costs which may be included are payments to union welfare fund, insurance, payroll taxes, and property taxes. O&M costs* for PCC may range approximately from \$0.60(8) to \$4.00(9) per ton of feed coal (\$0.75 to \$5.00 per ton of clean coal if the weight yield is 0.8). The lower figure is for coarse beneficiation, i.e., washing of +3/8-inch material only with the 3/8-inch x 0 fraction being shipped dry as is. The higher figure applies to full beneficiation of a coal with large amounts of -28-mesh material (above 20 percent) using heavy-medium circuits and full treatment of the fines.

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* 1977 dollars.

** Based on a combination of interest on borrowed funds and return on equity.

*** Cost per ton of cleaned coal is obtained by dividing the cost per ton of feed coal by the weight yield.

Cost of Btu Loss

The cost of Btu loss is a function of the cost and heating value of the feed coal and the Btu recovery (R). Formulas for calculating and reporting these costs have been shown by Battelle.(10) The costs for Btu loss as a function of the variables, weight yield and field coal cost, is shown in Table 4.

TABLE 4. COST OF BTU LOSS FOR R = 0.95
($/ton of Clean Coal)

F, Cost of Feed Coal, $/ton	100 Y, Weight Yield, Percent				
	60	70	80	90	95
10	0.83	0.71	0.63	0.56	0.53
15	1.25	1.07	0.94	0.83	0.79
20	1.67	1.43	1.25	1.11	1.05
25	2.08	1.79	1.56	1.39	1.32

The values in Table 4 reflect a cost which assumes that the value of Btu's associated with coal in refuse is equal to that of Btu's in clean coal. It should be recognized, however, that this is not a true relationship because constituents removed by PCC have a relatively low heating value and, being associated with sulfur compounds and inert mineral matter, they are difficult to utilize effectively. However, calculation of the cost for Btu loss without differentiation with respect to the actual value of Btu in the coal product versus those in the refuse gives a good approximation. It should be noted also that the cost of coal after washing is not simply a function of the cost of input coal and the amount of coal lost. For example, with a $20/ton cost of feed coal and an 80 percent weight yield, the cost of "raw materials" per ton of clean coal is $25.00. With a Btu recovery of 95 percent and a weight yield of 80 percent, the cost of Btu loss is $1.25/ton of clean coal. Part of the cost increase in raw materials of $5.00 is offset by a $3.75/ton increase in the value of the coal product (attributable to its higher heating value) giving a net cost of $1.25/ton of cleaned coal.

Total PCC Costs

The range in costs previously cited are summarized in Table 5.

TABLE 5. APPROXIMATE RANGES OF PCC COSTS

Cost Category	Approximate Cost Range, $/ton of clean coal
Capital Charges	0.44 - 2.79
O&M	0.75 - 5.00
Btu Loss	0.53 - 2.08
Total	1.72 - 9.87

The calculated value of fixed annual charges on capital is very sensitive to the estimated useful plant life and discount rate. Both the capital and O&M costs per ton of feed or clean coal are very sensitive to the estimated plant utilization. Thus, while most plants would fall in the cost range shown, the cost in specific situations are subject to further variation, as estimates for these parameters differ from the representative values used here.

BENEFITS OF PHYSICAL COAL CLEANING

The benefits associated with the use of physically cleaned coal include the following.

(1) Reduced coal transportation cost
(2) Reduced coal handling and coal pulverization cost
(3) Reduced ash collection and disposal cost
(4) Increased boiler efficiency, capacity, and availability
(5) Reduced boiler O&M costs
(6) Savings in cost for control of sulfur oxide pollution.

Items (1) through (5) above are savings in operating costs which result from general upgrading of coal quality. Item (6) is a savings which is realized where PCC is used to minimize sulfur pollution control costs. To date, there has been no comprehensive assessment of the value of all these benefits. A number of relevant studies have been conducted, however, and some understanding of the potential importance of some of the factors above is being developed.(11)

Penalties Associated With Poor Quality Coal

According to a recent study, power plants can experience incremental costs from poor coal quality starting at about $1.00 per ton for coal containing 13 percent minerals (ash + sulfur) and ranging to about $8.00/ton for coal containing 25 percent minerals.(12) These costs, which could be minimized by reducing the mineral content of the coal, are approximately in the range of costs shown in Table 5 for PCC. Based upon the study of cost penalties for poor quality coal(12), power plants using clean coal produced by PCC plants could expect to realize substantial cost reductions because of the amounts of ash and sulfur removed from the raw coal. However, accurate estimates of these cost reductions cannot be made because of insufficient data.

Savings in Sulfur Pollution Control

The control of sulfur oxide emissions from fossil-fuel-fired combustors currently is achievable by the use of one of four methods: (1) naturally-occurring low-sulfur coal; (2) flue gas desulfurization (FGD); (3) physical coal cleaning (PCC); and (4) combinations of these three approaches.

Evaluation of the relative merits of the different approaches requires that they be assessed from the standpoint of their impact on the cost of boiler output. Such a comparison which considers the impact of sulfur control on power generation was conducted by Battelle for this program.(10) Data derived from that study illustrated the possible magnitude of savings which could be realized using PCC alone, or with FGD, for sulfur oxide control.

The cost of power generation is determined by the capital charges, fuel cost, and O&M costs for the power plant. All three components are influenced in different ways by the method selected for sulfur oxide pollution control. Application of FGD increases both fixed charges and O&M costs but makes it possible to use readily available fuels. The use of PCC likewise increases both fixed and O&M costs for the total system but, when used in combination with FGD, reduces costs for the gas cleaning system. Also, it upgrades the quality of the fuel. The use of low-sulfur western fuels has no impact as far as increased fixed costs are concerned. Its use in boilers designed for eastern bituminous coal is judged, because of lower heating value and other properties to reduce boiler availability from 0.8 to 0.7 for purposes of the Battelle comparison. Some increased boiler maintenance might also be anticipated, but none is assumed for purposes of this comparison.

Because costs for generation of electricity are greatly dependent upon the hours the plant is operated, any comparison of sulfur oxide control methods must consider their effect on plant availability. The differences in availability reflect differences in coal quality or boiler and scrubber operation and the effect of scrubber operability on system availability. The effect of scrubbers was estimated for different degrees of redundancy as far as spare scrubber modules were concerned. The availability estimates used for the study are shown in Table 6.

Assumptions made for cost factors for the system configurations shown in Table 6 are shown in Table 7. The costs and benefits for PCC are generally consistent with data presented earlier. The relationship for incremental maintenance and mineral content and operating cost as a function of coal sulfur and mineral content is based on recent work reported for TVA boilers.(12) Other costs are considered reasonable in light of the latest estimates. The direct benefits shown for PCC include those discussed earlier such as reduced transportation costs, etc. The indirect benefits

TABLE 6. POSTULATED CONDITIONS OF AVAILABILITY(10)

Case No.	Case Description*	System Availability
1	Raw high-sulfur eastern coal, no FGD (baseline)	0.8
2	Raw low-sulfur western coal, no FGD	0.7
3	Cleaned high-sulfur eastern coal, no FGD	0.9
4	Raw high-sulfur eastern coal, with FGD (4 modules + 1 spare)(Boiler = 0.8, FGD = 0.65/module)	0.627
5	Cleaned high-sulfur eastern coal, with FGD (3 modules + 1 spare)(Boiler = 0.9, FGD = 0.75/module)	0.806
6	Cleaned high-sulfur eastern coal, with FGD (3 modules + 2 spares)(Boiler = 0.9, FGD = 0.75/module)	0.864

* Individual availabilities for boilers and FGD modules are given in parentheses where applicable.

are associated with FGD, e.g., reduced energy requirements for reheat of stack gases.

The overall comparison for the six system configurations is shown in Table 8. From results for the two cases comparing the use of ROM eastern coal and cleaned eastern coal (1 and 3), it is apparent that burning cleaned coal is the cheapest way to produce power. For those cases which achieve desired levels of sulfur oxide control, the advantage is even greater, ranging from 0.241 ¢/kWh to 0.563 ¢/kWh, even in situations where supplemental control with FGD is needed. These results are confirmed by a study being conducted by Bechtel National, Inc., for the Electric Power Research Institute, which concludes that "from the results obtained so far, it is judged that the cost of coal cleaning can be offset by savings in transportation costs, power plant capital costs, and operating and maintenance costs."(13)

In the development of these cost comparisons a number of simplifying assumptions were made which require that any conclusions reached be substantially qualified. First of all, the analysis applies only to utility

TABLE 7. SUMMARY OF COSTS FOR A 500-MW COAL-BURNING POWER PLANT(10)

Power Plant

Annual Fixed Charges - (0.235)(\$215,375,000) = \$50,663,000

Fuel
- Eastern high-sulfur coal - \$0.84/10^6 Btu
- Western low-sulfur coal - \$1.41/10^6 Btu

Production - (0.176)(Fuel Costs)/10^6 Btu

Incremental Maintenance - \$0.15 (% ash + % sulfur - 12.5)/ton of coal

Flue Gas Desulfurization System

Annual Fixed Charges
- Five modules - (0.235)(\$45,435,000) = \$10,688,000
- Four modules - (0.235)(\$40,485,000) = \$9,523,000

Operating and Maintenance - \$0.23/10^6 Btu

Physical Coal Cleaning

Capital Cost - \$15,870 per ton/hr

Annual Fixed Charges - (0.235)(\$6,852,500) = \$1,612,000

Operating and Maintenance - \$0.089/10^6 Btu

Direct Benefits - \$0.041/10^6 Btu

Indirect Benefits (when used with FGD) - \$0.031/10^6 Btu

TABLE 8. SUMMARY OF COSTS FOR POWER GENERATION USING VARIOUS CONTROL MODES (10)

Number	Case Description	Operating Hours per Year(b)	Power Plant Costs, ¢/kWh				FGD Costs, ¢/kWh		Coal Cleaning Costs and Savings, ¢/kWh				Total Costs, ¢/kWh
			Fixed	Fuel	Production	Incremental Maintenance	Fixed	O&M	Fixed	O&M	PCC Savings	PCC/FGD Savings	
1(a)	Raw high-sulfur eastern coal, no FGD (baseline)	7008	1.446	0.840	0.148	0.093	--	--	--	--	--	--	2.527
2	Raw low-sulfur western coal, no FGD	6132	1.652	1.410	0.248	--	--	--	--	--	--	--	3.310
3(a)	Cleaned high-sulfur eastern coal, no FGD	7884	1.285	0.898	0.158	0.015	--	--	0.041	0.089	-0.041	--	2.445
4	Raw high-sulfur eastern coal, with FGD (4 modules + 1 spare) (Boiler = 0.8, FGD = 0.65/module)	5493	1.845	0.840	0.148	0.093	0.389	0.230	--	--	--	--	3.545
5	Cleaned high-sulfur eastern coal, with FGD (3 modules + 1 spare)(Boiler = 0.9, FGD = 0.75/module)	7061	1.435	0.898	0.158	0.015	0.270	0.230	0.046	0.089	-0.041	-0.031	3.069
6	Cleaned high-sulfur eastern coal, with FGD (3 modules + 2 spares)(Boiler = 0.9, FGD = 0.75/module)	7569	1.339	0.898	0.158	0.015	0.282	0.230	0.043	0.089	-0.041	-0.031	2.982

(a) Not in compliance with NSPS promulgated December 23, 1971 (36FR24876).
(b) Based on Tables 6 and 7.

boilers which are required to meet the former NSPS of 1.2 lb $SO_2/10^6$ Btu or SIP regulations in this same range. Additional analysis will be needed to determine definitely that similar conclusions will apply to operation of commercial/industrial boilers and those utility boilers which will be subject to the recent NSSPS(14).

Also at least two areas of uncertainty are evident in the estimates of costs and benefits. First, the savings estimated for reduced boiler O&M costs (and associated increases in boiler availability) assume that these costs are a function of only the amount of ash and sulfur present in the coal. They are not based on results of operation with run-of-mine coal versus cleaned coal from the same source. Second, the estimates for the fixed, operating and maintenance cost for the FGD systems were based on average conditions and not related specifically to flue gas volumes to be treated, amount of sulfur oxide to be removed, etc. In any future analyses a more rigorous approach based on recent work by Kilgroe would be possible.(15)

It does not appear, however, that the elimination of uncertainties would substantially change the results. Additionally, the cost advantage for PCC indicated in Table 8 represents a potential annual savings of $9 million to $21 million for a 500 MW plant. The magnitude of national savings which appear to be possible is such that activity to promote the use of PCC would be in the national interest.

APPLICABILITY

Potential markets for low-sulfur, low-ash coal appears to be large, but the availability of cleanable coals in proximity to potential users is ill-defined. Further, the extreme sensitivity of coal cleaning economics to highly variable site-specific requirements is such that generalities can be misleading.

Potential market areas for physically cleaned coals include (1) utility boilers, (2) industrial and commercial boilers producing process steam or providing space heating, (3) metallurgical applications, and (4) systems converting coal into gaseious or liquid fuels. In 1975, U.S. boiler fuel consumption was approximately 26 x 10^{15} Btu (about 1/3 of the total for fossil fuels),(16) exceeding even transportation (19 x 10^{15} Btu) which is by far the next largest fuel use.(17) Coal-fired utility boilers burned about 430 x 10^6 tons of coal. Coal-fired boilers for industrial or commercial applications burned about 44 x 10^6 tons. Table 9 represents the breakdown of estimated fuel consumption, by usage sector and fuel type for the U.S. in 1975. From these data it is apparent that, despite the large amounts of coal burned, gas is used in about equal quantities as a boiler fuel, and gas and oil combined provided about 60 percent of the total. The ways in which patterns will change as gas and oil become unavailable or prohibitively expensive are very uncertain. It seems certain, however, that the use of coal will increase substantially, and it seems reasonable to assume that considerably more will be burned in small boilers which make up the industrial/commercial sectors where gas and oil consumption is now the dominant fuel.

TABLE 9. ESTIMATED FUEL CONSUMPTION FOR U.S. BOILERS (1975)(16)

Use Sector Fuel Type	Fuel Consumption, 10^{12} Btu
Utility	
Coal	9,310.0
Residual Oil	2,590.8
Distillate Oil	129.7
Natural Gas	3,016.7
	15,047.2
Industrial/Commercial	
Coal	1,101.6
Residual Oil	1,762.3
Distillate Oil	1,129.6
Natural Gas	6,381.2
	10,374.7

PCC is a potentially useful SO_2 emission control method for existing utility and large industrial boilers that are subject to state and local regulations but not subject to the 1971 new source performance standards (NSPS). For boilers where the 1971 NSPS are applicable, PCC is useful as a complementary control technique (e.g., along with FGD) in a number of situations.

For many of the smaller coal-burning boilers not subject to the 1971 NSPS (those less than 250×10^6 Btu/hr heat input), PCC may be the only feasible near-term method for minimizing SO_2 emissions and, therefore, may be used, or at some point even required, for control of such boilers. Boilers of this class represent an estimated 40 percent of the existing boiler fuel-burning capacity(16) and, with pressure to convert the 85 percent that are oil- or gas-fired to coal, the number of small coal-burning boilers can be expected to increase. Burning physically cleaned coal could be helpful in minimizing the pollution from such boilers by removing potential pollutants prior to combustion.

As conversion processes for generating gas or oil from coal begin to find application, it seems reasonable to suppose that they will create additional demand for physically cleaned coals. Removal of substantial amounts of sulfur, trace elements, and ash-forming minerals* from the coal prior to conversion is likely to be less expensive than putting such impurities through the system and having to remove them from discharge streams. In addition, there may be process-reaction reasons for using PCC. While such markets are likely to develop some years in the future, it seems reasonable to consider such applications as a part of the contribution that PCC can make to future environmental control.

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* PCC does not remove ash; it removes ash-forming minerals. However, common usage of the word "ash" in the coal cleaning industry to denote ash-forming minerals will be followed subsequently in this report.

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EXTENT OF DEVELOPMENT

Physical coal cleaning systems can be designed with reasonable confidence for well-characterized coals. Systems designed for removal of ash and pyritic sulfur may have circuits for treatment of three size fractions of coal: (1) coarse (e.g., 3 x 3/8 inch)*, (2) fine (e.g., 3/8 inch x 28M) and (3) ultrafine (e.g., 28 M x 0). Such arrangements are characteristic of systems which have been used for preparation of metallurgical coals. A more advanced system such as the multistream coal cleaning system (MCCS) at Homer City installed for utility service, is designed to provide an optimized strategy for meeting emission standards and utilizing coal resources. In this facility, two clean coal products, with low and medium sulfur contents, are developed for consumption in separate boilers which are regulated under different sulfur limitations. This system meets emission levels and maximizes recovery of Btu's from the raw coal. With a design capability of 1,200 tons per hour, this facility will process 5.2 million tons of run-of-mine (ROM) coal per year. It has a number of unique design features and incorporates four processing circuits which utilize heavy medium cyclones for processing of coarse and fine coal and hydrocyclones combined with wet concentrating tables for very fine coal.

The plant is expected to produce a medium sulfur coal and a low sulfur coal. Characteristics of the output streams are shown in Table 10. The medium sulfur coal will be used in two existing 600 MW generating units to meet the Federal and state emission regulation of 4.0 lb $SO_2/10^6$ Btu for existing boilers. The low sulfur coal will be used for a new 650 MW unit to meet the New Source Performance Standards (NSPS) of 1.2 lb $SO_2/10^6$ Btu without the use of a flue gas desulfurization (FGD) system.

The original plan for the new Homer City Unit No. 3 called for installation of an FGD system for SO_2 emission control. However, following comparative studies of the effectiveness and costs of FGD and MCCS for controlling SO_2 emissions from Unit No. 3, the plan to install FGD was dropped.

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* In practice, the size of coal fractions processed may vary widely. For purposes of this report, size ranges shown as examples are considered to be representative of coarse, fine, and ultrafine coal.

TABLE 10. HOMER CITY PLANT PERFORMANCE(7)

	Medium-Sulfur Coal	Low-Sulfur Coal	Refuse
Yield, weight percent	56.2	24.7	19.1
Recovery, Btu percent*	61.6	32.9	5.5
Product Btu/lb (dry basis)	12,549**	15,200	3,367
Ash, in Product, weight percent	17.8	2.8	69.7
Sulfur, in Product, weight percent	2.2	0.9	6.2
Pounds $SO_2/10^6$ Btu	3.6	1.2	36.5
Total Sulfur Reduction, weight percent	52.6	91.8	

* Figures account for 94.5 percent of Btu recovery. Overall plant Btu recovery is 93.5 percent which includes 1 percent loss for thermal drying.

** Mixture of middling and deep-cleaned coal.

As a sequel to the design and construction of this facility, a program to evaluate the performance of this advanced design will be undertaken. A cooperative program for this evaluation will involve the owners, the U.S. Environmental Protection Agency (IERL-RTP), the U.S. Department of Energy, and the Electric Power Research Institute. A 3-year period of performance for the evaluation is anticipated. It is expected that the results of the evaluation program will confirm the soundness of the design principles on which the plant is based.

The use of PCC systems for ash and pyritic sulfur removal is not, however, without technical limitations. Research and development aimed at improving these systems is being conducted by the U.S. EPA, the U.S. Department of Energy, and others. This work is intended to:

1. Define and evaluate the potential sources of pollution that are associated with PCC systems and assess the environmental impacts that might be associated with widespread application of the technology.
2. Collect additional information needed for full characterization of the washability of both existing coal supplies and reserves. While a substantial amount of testing has been completed for

some operating mines, all deposits now being mined have not been intensively analyzed. Very little work has been done to evaluate the washability of reserves not being mined.

3. Develop information needed to better understand the relationship between variability in the amount and type of ash and sulfur in the input coal and to develop improved systems for controlling the quality of the cleaned coal.
4. Generate background information needed to define the potential of new systems which employ presently available technology in configurations that involve crushing of the entire coal feed to a relatively fine size such as 3/8 inch x 0.
5. Develop information needed to define all the benefits associated with PCC including savings in pollution control costs, transportation costs, and boiler maintenance costs as well as savings associated with boiler availability.
6. Reduce the coal losses associated with coal cleaning and investigate ways to recover, or otherwise utilize, coal rejected by the cleaning process.
7. Determine the possible role of PCC in combination with, or in competition with, other emission control techniques such as flue gas desulfurization (FGD) systems or using clean fuels produced by advanced coal conversion systems.

ROLE OF COAL CLEANING IN SO_2 REGULATORY COMPLIANCE

In an evaluation of the potential role for coal cleaning as a means of controlling SO_2 emissions one must examine the capabilities of coal cleaning in the light of various existing and proposed SO_2 emissions regulations; determine the application in which the technology would be most useful; identify the barriers which exist to prevent wider application of coal cleaning; and describe actions which should be taken to overcome these barriers. The complete methodology and results of these evaluations are presented in Hall, et al.(18,10)

COAL AVAILABILITY

Existing facilities must meet SO_2 emission standards prescribed by the states in the State Implementation Plans (SIPs). The SIPs for SO_2 vary widely from state to state and often within a state. An evaluation of the usefulness of coal cleaning in providing compliance coal must consider not only the cleaning characteristics of coal produced in different regions but also the amounts of coal required by facilities under each of the various SIP regulations.

A "coal use" model was developed which relates the energy requirement of the facilities to the quantities of raw coal in the reserve and of coal that could be made available by application of various coal cleaning processes to meet the prescribed SO_2 emission standards.

As one example of the results obtained, four bar charts are shown in Figure 2 for facilities in the Northeastern U.S. using coal from the Northern Appalachian Region. The four bar charts in Figure 2 show the difference in the availability of compliance fuels for raw coal and for coal produced by three cleaning processes defined as follows:

(A) Physical coal cleaning using 1-1/2-inch mesh coal at 1.6 s.g.
(B) Physical coal cleaning using 3/8-inch mesh coal at 1.6 s.g.
if this produced coal to meet the standard; otherwise, 1.3 s.g.

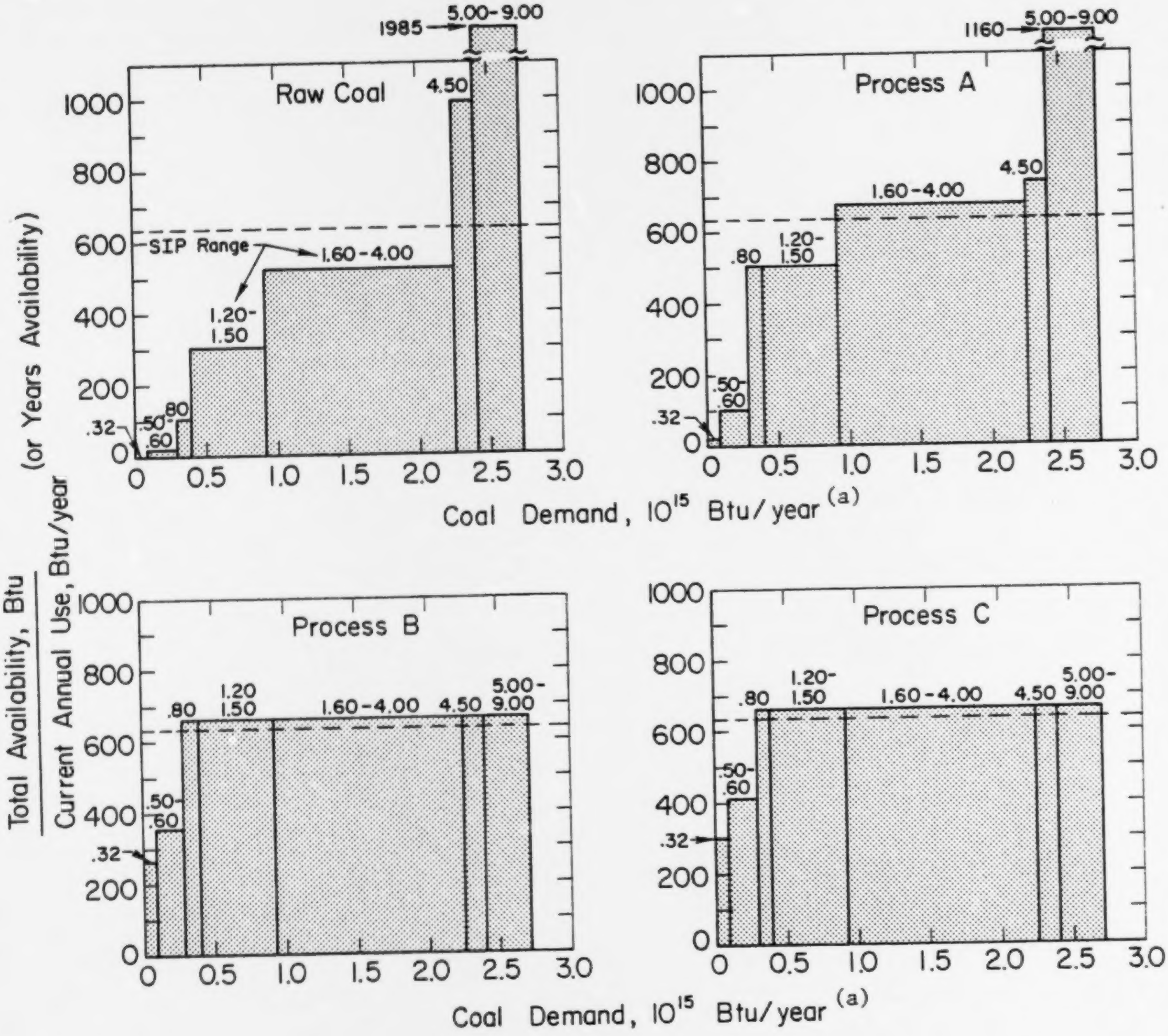

FIGURE 2. INCREASE IN THE QUANTITIES OF SIP-COMPLIANCE COAL ACHIEVABLE BY COAL CLEANING(10)
(see text for definition of processes)

(a) Northeast U.S. utility and industrial coal demand met by coal produced in the Northern Appalachian region.

was used. An operating penalty of 1 percent energy loss was assumed.

(C) Meyers process: for raw coal with greater than 0.2 percent pyritic sulfur, the level of pyritic sulfur is reduced to 0.2 percent. No sulfur reduction takes place if the raw coal pyritic sulfur level is less than 0.2 percent. A 5 percent energy loss was assumed plus an operating penalty of 2 percent energy loss and a weight loss of 10 percent.

In each chart the ratio of total coal to annual demand (or years of availability) is plotted against annual demand. The width of each bar represents the aggregate demand of all facilities in the region which operate under SIPs in the range shown at the top of the bar, while the height of the bar represents the number of years that compliance coal would be available if used at the current rates. The area of each bar represents the total quantity, in 10^{15} Btu, of coal in the reserves of the Northern Appalachian Region which can satisfy the SIPs in the indicated range. The horizontal dotted line shows the years of coal availability, at the current rates, if used without regard to sulfur content, and the area under the dotted line represents the total Btu's of coal in the Northern Appalachian reserve.

The charts show clearly the usefulness of these coal cleaning processes in producing coal to satisfy SIPs. The chart for raw coal shows that no coal in the region could be burned in compliance with a SIP of 0.32 (New Jersey, industrial, metropolitan areas), and only limited quantities of raw coal are sufficiently low in sulfur content that SIPs of 0.5 to 0.8 could be met. On the other hand, the charts for coal cleaned by Processes A, B, and C show progressively increasing quantities (increases in the shaded areas) of coal in compliance with low SIPs which can be produced by these cleaning processes. Results of this type were produced for eight real or hypothetical coal cleaning processes, for six regions, and for the entire United States. The value of coal cleaning as a means of satisfying SIP regulations is clear from these results.

COST COMPARISONS

The costs of the current technologically feasible SO_2 emission control methods naturally-occurring low-sulfur coal, FGD, PCC, and the combined use of FGD and PCC, were compared. In addition to the costs associated with each technology which are traditionally included in a cost analysis, emphasis was placed in this work on identifying and quantifying the benefits of coal cleaning which in the past have been ignored in comparative cost analyses. The benefits attributed to burning clean coal are as follows: (1) transportation costs are reduced since less coal is shipped due to the increased heating value; (2) ash disposal costs for the utility are reduced; (3) coal pulverizing costs are reduced; (4) benefits paid to the mine operations Pension and Benefit Trust Fund are reduced since fewer tons of coal are shipped from the mine to equal the same heating value; and (5) power plant maintenance costs are reduced by using coal with lower ash and sulfur content. Other indirect benefits to the power plant associated with burning clean coal result from increased plant efficiencies, longer plant life, and increased boiler availability.

In the event of a combined emission control system of physical coal cleaning and flue gas desulfurization, it becomes necessary to determine the effects of physically cleaned coal on the FGD system. The benefits to the FGD system result from a reduced quantity of flue gas to be treated and, consequently, units of smaller size and capacity may be used. Therefore, there will be reduced costs for energy, labor, chemicals, maintenance, supplies, overhead, working capital, sludge disposal, and land requirements for both the scrubber system and sludge disposal system.

For this analysis a single-unit power plant, having a nominal capacity of 500 MW was selected. For each alternative SO_2 control method, the system performance, availability and costs were evaluated. (See Table 8.) The results show that, when all costs and benefits to utilities of using physical coal cleaning are properly evaluated, a definite economic superiority for physical coal cleaning exists, even if supplemental application of another method, FGD, must be used to achieve full compliance with applicable NSPS or state implementation plans (SIP) emission limits.

In summary, the combined use of physical coal cleaning with FGD was significantly more attractive economically for the studied comparisons than either FGD alone or western low-sulfur coal. It also is very evident that in any case where physical coal cleaning alone can provide compliance with

NSPS or with state implementation plans, its use will provide the lower cost solution. However, in any specific case, the comparisons must be evaluated independently to account for site-specific variables such as coal composition, transportation requirements, and plant utilization.

BARRIERS TO EXPANDED COAL CLEANING

A number of factors which might inhibit expansion of the use of coal cleaning were examined. The common theme encountered is that of uncertainty. Investments in coal cleaning facilities may be deferred because of uncertainty regarding technical details, emission limits or other environmental regulations, or the ultimate profitability of the investment. The general types of barriers and a brief listing of examples of each will serve to summarize this work.

(a) Technical

- Lack of data relating washability results with commercial plant performance.
- Need for improved quality control techniques.
- Need for better techniques for separation of fine-sized pyrite.
- Need for more extensive data on benefits accruing to a boiler burning cleaned coal.

(b) Environmental

- Solid waste disposal requires control of leaching, fugitive dust emissions, and fires.
- Trace elements are concentrated in the refuse, a benefit with respect to the clean coal product, but require careful waste disposal.
- Land-use options in the immediate area of the cleaning plant are restricted.

(c) Transportation

- Increased coal use will place stress on the transportation system.

- Coal cleaning would help in mitigating the problem because of the higher Btu content per unit weight of cleaned coal.
- However, accelerated use of coal cleaning could add to the problem in certain areas in which cleanable coals predominate. For example, traffic from the Appalachian region to the middle Atlantic states would be expected to increase disproportionally as coal cleaning expands.

(d) Institutional

- PCC benefits may not be fully appreciated by potential investors.
- Commercial practicality of coal cleaning as a sulfur removal strategy may not be viewed as adequately demonstrated.
- Uncertainty regarding the Public Utility Commission's attitude regarding fuel cost pass-through if a utility were to invest in coal cleaning facilities.

(e) Economic and Social

- Coal cleaning does not now qualify for tax purposes as a pollution control investment.
- Some boiler operators may chose to purchase low sulfur coal from distant mines rather than clean local high sulfur coals.
- Capital may be difficult to raise because of the lack of information on commercial coal cleaning operations.

(f) Regulatory and Legislative

- Uncertainty regarding enforcement of SIPs, averaging periods, and variances.
- Uncertainty surrounding the permanence of any SO_2 emission standard.
- Uncertainty regarding air and water pollution standards for coal cleaning plants.

- Uncertainty over legislative incentives for the industrial use of coal.

NEEDED ACTIONS TO PROMOTE COAL CLEANING

The major conclusion from this work is that coal cleaning is an attractive method of SO_2 emission control, yet it is neither widely accepted nor used as such. In order to overcome the existing barriers to expanded use of coal cleaning, the Federal government could adopt one of the following approaches.

(1) Establish policies to insure that PCC is competitive in the marketplace.

(2) Or, as an alternative, establish a policy to require that all coal be cleaned physically before it is burned.

Nine technical research and development programs are recommended as necessary under either policy.

Specific initiatives designed to implement the policy to assure competitiveness of coal cleaning could include the following:

(1) The removal of the uncertainties regarding both SO_2 emission regulations and environmental regulations pertaining to coal cleaning plants.

(2) The establishment of loan guarantees which can be used under Section 102 of the Energy Policy and Conservation Act (EPCA) for centralized coal cleaning facilities to be used for processing the output of many small coal producers.

(3) The appropriation of funds to construct coal cleaning plants, after which the operation of these plants could be turned over to industry on a pay-back-as-run basis.

(4) The establishment of legislative provisions for a lower income tax rate or for direct subsidies based on the percent of sulfur removed prior to the sale of the coal.

(5) A reversal of the Internal Revenue Service position which does not allow coal cleaning plants to qualify as pollution control investments for tax purposes.

(6) A change in ICC regulations allowing rail shipment of cleaned coals at unit train rates.

(7) The creation of a public information program to educate utilities and potential industrial users about the benefits of burning cleaned coal.

The policy to require that all coal be cleaned has merit on these general grounds:

- Coal cleaning is the least-cost method for achieving moderate, but significant, reductions in sulfur emissions from existing coal-fired boilers.
- Cleaned coal could be used immediately in existing facilities. There are essentially no "retrofit" problems. Thus, reduced SO_2 emissions can be achieved as soon as cleaned coal becomes available. In contrast, the New Source Performance Standards will not materially affect total SO_2 emissions until a significant fraction of existing boilers are retired and replaced.
- State-of-the-art coal cleaning methods could reduce uncontrolled emissions of SO_2 from coal-burning facilities by an estimated 32 percent if all coal were cleaned physically. Even greater reductions would be accomplished if advanced processes capable of reducing organic sulfur are developed.
- Scrubbers, operating at 85 percent sulfur-removal efficiency, would have to be installed on 38 percent of the entire coal-burning capacity to achieve an equivalent reduction in SO_2 emissions.
- The use of cleaned coal is expected to extend boiler life, improve efficiency, and increase the capacity factor, all significant conservation benefits.

Congressional action would be necessary to mandate nationwide coal cleaning. The technology-related research and development recommended must be completed so that the mandated technology is fully available and demonstrated. Finally, measures designed to assure that capital is available for construction of coal cleaning plants will be required. These could include loan guarantees, accelerated depreciation schedules, product price supports, or other measures.

POLLUTION CONTROL TECHNOLOGY*

One of the main purposes of coal preparation is to reduce the potential pollutants in raw coal prior to its utilization so that the emissions from utilizing the coal can be reduced. Coal preparation involves environmental trade-offs; i.e., the potential pollutants are being transferred from one environmental medium to another. Through coal preparation, highly mobile air pollutants which may be discharged by the burning of raw coal are converted into solid refuse or waste water, from which the pollutants may be easier to control than air pollutants. However, the waste materials generated by coal preparation in themselves can be important sources of environmental contamination.

In order to evaluate the full implications of coal preparation as a viable pollution control measure, the extent of environmental contamination associated with coal preparation and the control technology for this source of contamination should be adequately assessed. The potential emissions from various physical coal preparation activities and the applicable pollution control technologies for minimizing adverse effects from these sources must be considered. Emissions of potential pollutants from existing coal preparation plants, storage, transportation and handling facilities, and solid waste disposal areas can be drawn upon for comparative analyses.

Over one thousand potential pollutants associated with coal preparation and coal utilization have been identified.(20) However, very limited information is available to quantify the emission rate of specific pollutants from an individual coal cleaning process. Furthermore, even if some emission data for a specific operation are reported in the literature, they are not necessarily representative of the entire coal industry because of the inherent heterogeneity of coal and a wide variety of different process schemes. Thus, meaningful estimation of pollutant emission rates requires very extensive emission data which are obtained from many different locations and operating conditions with many different raw coals.

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* Content supported by Battelle reports, "Environmental Assessment of Coal Cleaning Processes: Technology Overview"(1); "Pollution Control Technology for Coal Cleaning Processes"(19); and "Criteria for Assessment of Environmental Pollutants from Coal Cleaning Processes"(20).

AIR POLLUTION CONTROL TECHNOLOGY

Several types of air pollution control devices are available for application to coal cleaning operations. The choice of the control device depends on the type of pollutant (particulate or gaseous), the properties of the pollutant (such as size, density, and shape for particulates, and equilibrium solubility, reactivity, and adsorptivity for gases), and the properties of the conveying medium (such as density, temperature, and velocity). Particulate control devices may be broadly classified as dry inertial collectors (gravity settlers and cyclones), filters, and wet scrubbers. Electrostatic precipitators cannot be used in coal cleaning facilities due to the potential explosive hazard with the coal fines. Control devices for the removal of gases or vapors involve adsorption or absorption in a variety of contacting devices. Table 11 provides a general outline of the mechanisms and types of equipment in common use today for the removal of the two basic air pollutant types.

TABLE 11. CLASSIFICATION OF EMISSION CONTROL EQUIPMENT(21)

Control of Particulates	Control of Gases and Odors
Dry inertial collectors	Dry adsorbers
Gravity settling chambers	Dry absorbers
Cyclones	
Fabric filters	
Wet inertial scrubbers	
Impingement	
Centrifugal	
Venturi	
Self-induced	

Several factors must be considered in the evaluation of equipment for controlling the air emissions from coal cleaning processes. Important factors are (1) characteristics of air emissions and operational constraints, (2) control technology removal efficiency, (3) capital and operating costs, and (4) disposal of wastes.

Five major sources of air pollution have been identified for coal cleaning processes; they are

- Crushing and sizing
- Pneumatic cleaning
- Thermal drying
- Coal storage, transportation, and handling operations
- Coal waste disposal areas.

In general, the fugitive emissions from coal storage, transportation and handling operations, and solid waste disposal areas are not amenable to treatment by air pollution control devices. The most practical way of controlling these fugitive emissions is prevention.

The air emissions from each of these three sources vary somewhat, but certain generalizations can be made as to their characteristics. Typically, the crushing and sizing operations produce dry, small particulates (0.5 to 6.0 microns) at ambient temperature. The quantity of dust generated depends on the coal type, moisture level, and type of sizing and screening operations. In the pneumatic cleaning operations, large volumes of dry particulates (~120 gr/dscf) are generated with particle sizes up to 100 mesh. The thermal drying operations produce high volumes of particulate emissions (50 to 200 gr/dscf) at high moisture levels and temperatures above 200 F. Combustion gases containing SO_2, NO_x, and CO, produced from the coal fuel, also accompany the particulates. These emission characteristics dictate to a significant degree the type of technology most applicable for their control. Factors such as temperature, humidity, particle size distribution, loading, and the potential for an explosion pose operational constraints on the control equipment.

Depending on its characteristics, disposal of the particulate wastes collected by the control device can present new potential pollution problems. For control devices on pneumatic cleaners and thermal dryers, disposal of the waste generally is not a problem as the collected particulates consist primarily of coal and are usually combined with the clean coal stream. For control devices on the crushing and sizing operations, the collected solids may be high in impurities and could require disposal. The more appropriate processes are those that produce waste that is easy to handle, dispose of, or treat with minimal environmental abuse.

Table 12 shows the installed capital costs and operating costs for air pollution control equipment for hypothetical 500 and 1000 tons/hr coal cleaning plants with the following levels of treatment: (1) crushing and sizing, (2) medium size coal beneficiation with air tables, and (3) fine size coal beneficiation with thermal drying.

For the first two types, more than one particulate control device is applicable; in this case, cost estimates are shown for each type of treatment. For the third type, an additional cost was included to account for flue gas desulfurization on the thermal dryer. Limestone scrubbing was selected as the basis for the cost estimate because of its more developed state.

WATER POLLUTION CONTROL TECHNOLOGY

Coal cleaning operations produce two types of water pollutants: suspended materials (solid or liquid) and dissolved substances. The technology available for removing suspended materials from water includes mechanical dewatering, sedimentation, and flotation. Dissolved substances can be removed from water or converted to less objectionable forms by a range of techniques from the simple and routine to the expensive state of the art. These include neutralization, adsorption, ion exchange, reverse osmosis, freezing, or biological treatment. Table 13 lists the technologies currently in use or potentially applicable for treating coal cleaning wastewater. Information relevant to choice of method includes removal efficiency, operational constraints, and costs. Significant emission sources must be matched with potential water treatment technologies. Each source/technology pair can be evaluated with respect to anticipated performance, secondary emissions, and capital and operating costs for typical coal cleaning plant configurations.

TABLE 12. ESTIMATED COSTS OF AIR POLLUTION CONTROL EQUIPMENT FOR COAL CLEANING PLANTS(a)

Emission and Operation	Applicable Control Equipment	Installed Cost of Control Equipment, Dollars (1977)/ton/hr		Annual Operating Cost of Control Equipment,(b) cents/ton	
		500 tons/hr	1000 tons/hr	500 tons/hr	1000 tons/hr
Dust from crushing and sizing operation	Dust enclosures with dry bag collectors	52	36	0.2	0.1
	Dust enclosures with high-efficiency wet scrubbers	30	20	0.2	0.2
Air tables operating on medium-size coal	Primary cyclones followed by dry bag collectors	400	360	2.8	2.8
	Primary cyclones followed by high-efficiency wet scrubbers	220	200	10.0	9.7
Thermal dryers associated with fine size coal beneficiation	Primary cyclones with high-efficiency wet scrubbers	270	250	12.5	12.2
	Primary cyclones with high-efficiency wet scrubbers followed by limestone scrubbing	9450	9250	93.8	93.8

(a) Source: Min, et al.(19)

(b) Excludes capitalization, depreciation, and interest. Based on 180 (2-shift) days.

TABLE 13. CLASSIFICATION OF WATER TREATMENT TECHNOLOGIES(19)

Control of Suspended Materials	Control of Dissolved Materials
Mechanical dewatering	Neutralization
Centrifuges	Adsorption
Cyclones	Ion exchange*
Screens	Reverse osmosis*
Filters	Freezing*
Sedimentation	Biological oxidation
Settling ponds	
Sedimentation tanks (thickeners)	
Flocculation	
Flotation	

* Not known to be in current use, probably because of high costs.

Leachate

Leachate from coal preparation refuse is variable and dependent upon the raw coal from which it is derived as well as rainfall and other factors. However, because of the heavy metals concentration in coals in general and the fact that many of the highly toxic metals such as mercury and lead are generally associated with the mineral fraction, the leachate from the refuse can be expected to be high in metal ions. This is especially true if the leachate is acidic, as most of the metallic minerals are quite soluble in acid. However, leachate test results from fluidized-bed combustion residues, which contain most of the materials expected in coal preparation refuse but are alkaline, also show significant concentrations of metals.

It is possible to minimize leachate production from a disposal facility by (1) diverting away all surface drainage, (2) applying a cover material to prevent infiltration of rainfall, (3) grading to promote rapid run-off (but not so rapid as to create excessive erosion), (4) minimizing the open (working) area, and (5) applying a vegetative cover upon completion of an area.

As an alternative to minimizing the leachate, or preferably in addition to minimizing the leachate, a leachate collection and treatment system can be installed. In most cases, a naturally impermeable soil, or in some cases a synthetic liner, is used to prevent infiltration of the leachate into the ground and eventually the groundwater. An underdrain system is needed to gather the leachate and carry it to a leachate treatment system.

The leachate treatment system will be preceded by a leachate collection pond. The pond acts to equalize the leachate flow, catching peak volumes associated with rainfalls and feeding leachate at a relatively uniform rate to the actual treatment process. Leachate treatment will probably consist of lime neutralization and settling. As well as improving pH, lime treatment also will remove large quantities of metal ions, which are relatively much less soluble at higher pH levels. However, if metal ions and other constituent concentrations, such as total dissolved solids, remain at levels too high to discharge, additional physical or chemical treatment may be required. Examples of treatment processes used on acid mine drainage, for example, include reverse osmosis, ion exchange, and alumina-lime-soda processing.(22) Settled solids may be returned to the disposal area but may require chemical fixation by any one of a number of commercially available products to avoid redissolving the metals.

Water Pollution Control Costs

Table 14 shows the estimated costs of water pollution control equipment for hypothetical 1000 ton/hr coal cleaning plants with configurations as follows: (1) crushing and sizing with dry screening and wet beneficiation and (2) medium size coal beneficiation with wet screening and wet beneficiation.

In generating the treatment costs, it has been assumed that all water treatment is performed to satisfy environmental constraints. Actually,

TABLE 14. ESTIMATED COSTS OF WATER POLLUTION CONTROL EQUIPMENT FOR SELECTED 1000 TPH COAL CLEANING PLANTS

Plant Type	Effluent	Quantity, gpm	Applicable Control Equipment	Installed Cost of Control Equipment, (1977 Dollars)	Annual Operating Cost of Control Equipment,[b] cents/ton
Crushing and Sizing with Dry Screening and Wet Beneficiation	Process Water Flow-Suspended Solids	3,450	Radial flow thickener	345,000	0.8
			lagoon, or	108,000	0.6
			froth flotation	33,000	0.7-1.4
	Dissolved Solids		Absorption-activated carbon treatment	1,700,000[a]	2.0
Crushing and Sizing with Wet Screening and Wet Beneficiation	Process Water Flow-Suspended Solids	7,650	Mechanical dewatering-hydroclones,	150,000	0.6
			microscreens, or	230,000	0.4
			pressure filters	310,000	0.8
			Thickener or	510,000	0.6
			lagoon	160,000	0.4
Fine Size Coal Beneficiation with Hydrocyclones and Thermal Drying	Process Water Flow-Suspended Solids	9,250	Radial flow thickener	560,000	0.5
			or lagoon	180,000	0.3

(a) Adsorption is not presently used to treat coal cleaning process water, and would not be necessary for treating the recirculating process water for any plant with a closed water circuit.

(b) Including depreciation and interest on capital.

much of the treatment, particularly the dewatering treatment, is necessary for operation of the coal cleaning processes. Thus, a portion of the costs cited may be attributed to process requirements rather than environmental requirements. Furthermore, since the use of a closed water circuit is a viable alternative to treatment and release of wastewater, the water most likely to be treated for release to the environment is run-off and leachate from coal storage and coal refuse piles.

SOLID WASTE CONTROL TECHNOLOGY

Coal production in the United States in 1974 was nearly 590 million tons, exclusive of anthracite. Of this amount, some 290 million tons were cleaned by mechanical means. This resulted in an estimated 96 million tons of coal preparation refuse.(23) Although the refuse varies physically and chemically depending upon coal source, preparation process, and other factors, the refuse generally contains waste coal, slate, carbonaceous and pyritic shales, clay, and other impurities associated with a coal seam.

Depending upon the degree of size reduction employed in the coal cleaning process, refuse may be coarse (+28 mesh) or fine (-28 mesh). Coarse refuse may be generated dry, or if generated in a wet process, drains fairly readily. Coarse refuse is usually disposed of in an embankment or landfill. Fine refuse is generated by wet processes, and is generally removed from the preparation plant as a thickener underflow and impounded into nearby settling ponds. In many cases the settling pond is impounded by a coarse refuse embankment.

Since the 1972 Buffalo Creek disaster at Saunders, West Virginia, in which a coal waste embankment failed, causing heavy losses in lives and property, greater emphasis has been placed on stability of coal waste embankments.(24) The U.S. Bureau of Mines investigated the physical properties of coal refuse with regard to structural stability.(25,26) Engineering considerations on construction of coal waste embankments have also been published.(27) This consideration as well as Federal water pollution and solid waste regulations now are causing most preparation plants to employ dewatering methods for the fine refuse and to dispose of the dewatered fine refuse along with the coarse refuse in landfills or non-impounding embankments. In addition to the improvement of waste disposal practices, current research in waste handling has been aimed at finding means of utilizing the coal, pyrite, and other mineral values in the wastes.

It is the purpose of coal preparation to remove impurities from the coal, and the unfortunate corollary is that the impurities must then be disposed of as refuse. Coal preparation refuse can be expected to contain all of the inorganic substances found in the raw coal and, generally, in more concentrated form.

An important constituent of coal preparation refuse is sulfur. Sulfur occurs in organic and inorganic forms in coal. Physical coal preparation removes primarily the inorganic forms, pyrite and marcasite. These may be present in quantities from less than 0.1 percent to as much as 7.1 percent by weight.(28) The presence of these sulfur compounds has important implications for acid generation from the refuse.

Other important constituents of physical coal preparation refuse are the trace elements. The trace elements found in coal refuse are not uniformly distributed. Some elements, particularly Ge, Be, and B, have been found to concentrate in the organic fraction of coal and, therefore, are not likely to be as abundant in the refuse. A second group of trace metals, including Hg, Zr, Zn, Cd, As, Pb, Mn, Mo, Si, Al, Ca, and Fe, tends to concentrate in the mineral matter and therefore in the refuse. A third group, containing Ti, Sb, Ni, Cr, and others, tends to be divided between the organic and the mineral fractions.(29)

Generally, the environmental problems caused by land disposal of any waste including coal refuse fall into these gategories: aesthetics, blowing dust and debris, putrescense, odor, potential for breeding or harboring rats or insects, gas generation, fire potential, erosion, leachate, and final land use.

The potential aesthetic impacts are largely site-dependent. Good disposal practice would have the working area of the disposal facility held to a minimum and other areas kept vegetated until needed and revegetated upon completion. However, coal refuse disposal areas will typically be much larger than municipal sanitary landfills. For example, a moderate-sized facility may generate 3000 tons per day of coal preparation refuse, while a sanitary landfill handling half that amount would be considered very large. Therefore, the open working area will necessarily be quite extensive. Isolation of the site, by distance or by physical barriers, is the only solution to the aesthetic problem. This can be assured only by careful site selection.

The refuse generated by a coal preparation plant contains considerable quantities of fine particles. Often these are handled dry or, if handled wet, they drain and dry fairly rapidly, leading to potentially serious fugitive dust problems. Site selection is partly the solution to this problem. For example, if a valley fill is used, as is commonly practiced, the orientation of the valley with respect to prevailing winds should be considered. A crusting agent has been employed to prevent water infiltration into and fugitive dust from coal piles.(30) The crusting agent is an acrylic polymer which is sprayed on the surface of the pile; it might equally be applied to coal refuse.

Putrescence and odor from coal preparation refuse are not generally a problem. Similarly, rodents and insects are not attracted to the refuse either as a food source or as a particularly good harborage.

Gas generation within the refuse has not been identified in research so far as a potential problem. However, as there still remains a considerable amount of coal in the refuse, fire in the refuse banks is a matter of great concern. Fires occur primarily by spontaneous combustion due to the reaction between the coal and oxygen from the atmosphere. Compacting the coal preparation refuse piles will minimize air circulation and reduce the likelihood of fire. In addition, sealing the pile, either with an occasional soil covering or with a crusting agent, also can reduce the fire potential.(30)

The angular particle shape of coal preparation refuse allows it to be placed in fairly steep embankments, sometimes as steep as 30 to 35 degrees. These steep slopes may be subjected to very high wind pressures, increasing the circulation of oxygen within the pile and thereby increasing the likelihood of fire.(31) Reducing the grade of exposed banks may therefore be another way of reducing fire potential of coal preparation refuse.

Erosion of the disposal area surface may be a problem. The particle sizes of the refuse are particularly susceptible to erosion. Diversion ditches to minimize flow of water over the refuse surface, as well as siltation basins to capture eroded material, are essential. The supernatant liquid (leachate) from the siltation basin should be monitored for high pH, sulfate, calcium, total dissolved solids, and heavy metals before being discharged to the environment. Treatment of this liquid may be necessary. Leachate production and treatment needs were discussed previously under Water Pollution Control.

Costs of Disposal and Reclamation

The Bureau of Mines has studied the costs to the coal industry of refuse disposal and reclamation. Nine coal waste disposal projects of mining companies were investigated and the results are summarized in Table 15. These results show refuse disposal costs ranged from 13 to 39 cents per ton-mile, spreading and compacting ranged from 4 to 28 cents per ton, and soil covering and planting ranged from $9,070 to $2,319 per acre.(32) These costs did not include the cost of installing or operating leachate collection or surface drainage collection and treatment facilities.

Costs have also been reported by the Meadow Mining Company for refuse disposal from their preparation plant at Beckley, West Virginia. That plant has a 600 tph capacity and is expected to average 35 percent reject throughout its lifetime. Operating costs were not reported, but labor costs were estimated at over $125,000 per year.(33)

A report done by the Institute of Mining and Minerals Research at the University of Kentucky stated that coal refuse disposal costs ranged from $0.50 to $1.00 per ton, although specific disposal methods were not described.(34)

TABLE 15. COST OF COAL REFUSE DISPOSAL (INDUSTRY)(32)

Company	Mine Location	Mine Name and Type	Refuse Produced, tons/day	Mode of Transportation	Distance to Disposal Site (One Way), miles	Refuse Disposal Cost, $/ton mile (1977 Dollars)
Bethlehem Mines Corporation	Barrackville, West Virginia	Idamay mine No. 44 (underground)	1,100	Truck	1.0	$0.39
	Ellsworth, Pennsylvania	Mine 60(a) (underground)	2,800	Truck and aerial tram	1.0 0.5	0.24 0.14
Beth-Elkhorn Corporation	Jenkins, Kentucky	Hendrix No. 22 (underground)	765	Truck	1.0	0.18
	Jenkins, Kentucky	No. 27 mine (underground)	1,170	Conveyor belt and truck	1.0	0.18
Eastern Associated Coal Corporation	Rachel, West Virginia	Joanne mine (underground)	600	Truck	1.0	0.23
Hanna Coal Company	Cadiz, Ohio	Georgetown Area (strip mine)	4,164	Truck	1.0	0.35
Pittsburgh & Midway Coal Mining Company	Hallowell, Kansas	Mine 19 (strip mine)	2,400	Truck	2.0	0.14
	Madisonville, Kentucky	Colonial mine (strip mine)	1,100	Truck	2.0	0.14
U.S. Steel Corporation	Uniontown, Pennsylvania	Ginger Hill (underground)	4,500	Underground rail mine cars and carryall	4.0	0.13(b)

(a) Abandoned dumps; refuse from Mines 51 and 58 being disposed at Mine 60 dump by aerial tram.
(b) Direct cost only.

SAMPLING AND ANALYSIS*

An environmental field testing program was designed for coal cleaning facilities throughout the United States with the objective of eventual acquisition of information on the pollutants associated with effluents from a variety of types of coal cleaning facilities and their associated coal transportation, storage, and refuse disposal areas. Sampling designs call for the establishment of sites both upstream and downstream of pollution control equipment and points of application of waste treatment techniques with the objective of determining the effectiveness of these pieces of equipment or techniques in reducing the potential pollution loading on the environment. Effluents of interest include leachate and runoff from coal storage and refuse disposal piles; leachate from slurry holding and disposal ponds; and fugitive dust or gases from coal transportation and handling, storage piles, refuse piles, and plant operations. Thermal dryer gases and particulates will be sampled at selected plants where these devices are used (Table 16).

In summary, the objectives of the environmental testing program (source identification, quantification, and assessment) are

- to produce supporting data for the overall program from coal cleaning plants in a variety of environmental and technological situations, specifically data on effluent streams which may impact the environment;

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* Content supported by Battelle reports: "Criteria for Assessment of Environmental Pollutants from Coal Cleaning Processes"(20); "Environmental Assessment of Coal Cleaning Processes: Test Program Development"(35); "Environmental Assessment of Coal Cleaning Processes: Selection of Sites for Source Test Program"(36); "Environmental Assessment of Coal Cleaning Processes: Sampling and Analysis Methods"(37); "Environmental Assessment of Coal Cleaning Processes: Source Test Program"(38); "Test Plan for Level 1 Environmental Source Assessment of the Homer City Coal Cleaning Facility (Site Category 1)"(39); and "Environmental Assessment of Coal Cleaning Processes: Homer City Power Complex Testing"(40).

TABLE 16. POLLUTANT SOURCES AND TYPES OF POLLUTANTS (35)

Source	Potential Pollutants
Solid waste piles	Acid water runoff Dust and particulates Gases and odors
Coal storage piles	Dust
Waste pile runoff	Suspended solids Dissolved solids Metal ions Acidity Organic compounds
Plant process water	Suspended solids Acidity Alkalinity Metal ions Dissolved salts Organic compounds
Thermal driers	Particulates Trace elements Organic compounds
Crushers and screens	Noise Dust

- to support trade-off studies with field data that will help evaluate the effectiveness of pollution control equipment and waste management techniques used at coal cleaning plants and their associated facilities; and
- to characterize effluent streams using Level 1 grab sampling techniques and Level 1 chemistry and bioassay analytical techniques (Level 1 EPA Preliminary Environmental Assessment (41-44)).

The field testing program is intended to characterize physically and chemically, and determine relative toxicity of, effluent streams sampled at their respective sources, rather than to characterize air, water, and biological quality in the general vicinity of the cleaning plant as would be a typical environmental impact assessment under National Environmental Policy Act (1969) approaches. Therefore, results of the present testing program could not be used to evaluate cause/effect relationships between effluent streams and ecological effects observed in the field. Laboratory tests, however, can provide information on the relative toxicity of effluents to aquatic and terrestrial biota. In addition, long-term objectives include those directed at the detailed analysis of cause/effect relationships in the field. Future field studies of this type will require an analysis of effluent streams after they have had a chance to disperse, degrade, biomagnify, and intermix with other effluents in the surrounding environment.

CRITERIA FOR ASSESSMENT(20)

The fundamental criterion for assessing environmental pollutants associated with coal cleaning is the relationship between each expected environmental concentration and the maximum concentration which presents no hazard to man or biota on a continuous long-term basis. This threshold concentration is designated as the estimated permissible concentration (EPC).

While simply stated, this concept represents a rather complex utilization of a number of subcriteria dealing with specific phases of the overall problem:

- Selecting those environmental pollutants of most concern,
- Selecting methods for estimating environmental concentrations of pollutants resulting from coal cleaning, and
- Selecting methods for evaluating the EPC's for man and biota.

The pollutants most needing control must be identified, either because of the quantities emitted or their toxicities, or both. Also, almost by definition, substances designated as pollutants by EPA are candidates for control. Data on the quantities and concentrations of those pollutants emitted to the environment are needed. Estimates of environmental concentrations of pollutants in all three media--air, water, and land--also are needed.

Estimation initially requires physical transport and dispersion models. Ecological transport and distribution is much less well-studied and there are gaps in the data for many elements and many species. Qualitatively, the pathways and mechanisms for accumulation and dispersal have been identified; the problems arise in attempting to quantify these mechanisms.

One of the most critical information needs is data on the toxicities of the individual pollutants, from which estimated permissible concentrations (EPC's) can be derived. Also needed are improved methods for converting toxicological data to the threshold levels represented by EPC's, and biologically supported safety factors for incorporation into the formulae. Decision criteria are needed to determine the relative priorities to be assigned to controlling specific pollutants. Compiling and analyzing the data mentioned above will lead to these criteria.

Prioritization of Pollutants

The pollutants directly associated with coal cleaning are primarily inorganic compounds associated with the ash fraction. Water will be the major receptor of these pollutants; operations causing major emission of air pollutants are infrequent in coal cleaning. The largest air emissions will arise as particulates from thermal dryers and as fugitive dust from coal storage and refuse piles and coal handling. The reverse situation is true in the ultimate combustion of coal; air emissions, particularly SO_2 and suspended particulates, are of much more concern than water effluents.

Lists of potential pollutants from coal cleaning and utilization containing hundreds of entries have been compiled. To arrive at a more manageable number, a "Priority 1" list (Table 17) was selected to include those elements and substances already identified as pollutants of concern, and whose presence in finite concentrations in coal cleaning processes is known or highly suspected. This list contains 49 elements and 23 substances or groups of substances, the latter including such well-known items as SO_2, total suspended particulates (air), and total suspended solids (water).

Although the Priority 1 list satisfies the requirement of a manageable list containing the important pollutants expected from coal cleaning processes, there appeared to be a need for an even more abbreviated list suitable for

TABLE 17. PROPOSED PRIORITY 1 POLLUTANTS FOR COAL CLEANING PROCESSES(20)

Elements	Specific Pollutant Limitations(a) A	B	C	D	E	F	G	H
Aluminum								
Antimony		X					X	
Arsenic		X			X		X	X
Barium		X			X			X
Beryllium			X				X	X
Boron		X						X
Bromine		X						
Cadmium					X	X	X	X
Calcium		X						
Carbon								
Cerium								
Cesium								
Chlorine		X						X
Chromium		X(b)			X		X	X
Cobalt		X(b)						
Copper		X(b)					X	X
Fluorine		X						
Gallium								
Germanium								
Indium								
Iodine		X						
Iron					X			X
Lanthanum								
Lead					X		X	X
Lithium								
Magnesium								
Manganese		X			X			X
Mercury			X		X	X	X	X
Molybdenum		X						
Nickel		X					X	X
Nobium								
Nitrogen								
Oxygen								
Phosphorus								X
Potassium								
Rubidium								
Selenium					X		X	X
Silicon								
Silver							X	
Sodium								
Strontium								
Sulfur								
Tellurium		X						
Thallium							X	
Thorium								
Tin								
Titanium		X						
Uranium		X						
Vanadium		X						
Zinc		X			X		X	X
Zirconium		X						

Groupings	Specific Pollutant Limitations(a) A	B	C	D	E	F	G	H
Alkalinity								X
Ammonia		X						X
Cyanide		X			X	X	X	X
Chlorides					X			
Nitrates					X			X
Sulfides								
Sulfates					X			
SO_x	X	X						
NO_x	X	X						
Total Suspended Solids (TSS)								
Total Dissolved Solids (TDS)					X			
Chemical Oxygen Demand (COD)								
Total Suspended Partic. (TSP)	X			X				
Carbon Dioxide		X						
Carbon Monoxide	X	X						
Hydrocarbons	X							
Photochemical Oxidants	X							
Oil and Grease								X
Phenols		X			X			X
Organic Sulfur Compounds								
Organic Nitrogen Compounds								
Polycyclic Organic Materials (POM's)								
Carbon Chloroform Extract (CCE)					X			

(a) Column headings are defined as follows:
- A - National Primary and Secondary Ambient Air Quality Standards(52)
- B - OSHA Standards for Workroom Air Contaminants(53)
- C - National Emission Standards for Hazardous Air Pollutants(54)
- D - New Stationary Source Performance Standards (Coal Preparation Plants)(55)
- E - Interim Drinking Water Regulations (EPA)(56)
- F - EPA Toxic Pollutant Effluent Standards (Proposed)(57)
- G - EPA Toxic Pollutant List(58)
- H - EPA Water Quality Criteria (Proposed--not regulations)(59)

(b) Metal as fume or dust.

preliminary testing of some of the concepts and approaches to environmental assessment. To meet this need, an abbreviated "short list" has been proposed which includes the following chemical pollutants:

- Arsenic
- Beryllium
- Cadmium
- Iron
- Mercury
- Lead
- Manganese
- Selenium
- Sulfate sulfur
- Sulfur dioxide
- Nitrate nitrogen
- Nitrogen oxides

This list, which includes both air and water pollutants, is suitable for the evaluation of chemical and physical transport models, as well as estimated emissions and permissible concentrations.

The importance of a pollutant is a function not only of its toxicity but also of its abundance. Thus, the quantities of the pollutants cited above in coal are an important parameter. Unfortunately, there is no simple measure of abundance; the composition of coals varies greatly, not only from region to region, but also from seam to seam and within a seam. Thus, analysis and comparison demand recourse to averages and ranges about those averages. The geometric mean concentrations listed in Table 18 for the eight elements on the Priority 1 "short list" are illustrative. Even though there are fairly large variations, the order of magnitude is consistent, suggesting that these averages are suitable for generic, non-site-specific environmental assessments.

TABLE 18. GEOMETRIC MEAN CONCENTRATIONS OF EIGHT ELEMENTS IN COAL(20)

	Concentration, ppm		
	Illinois Basin	Appalachian	Western
Arsenic	7.4	15	1.5
Beryllium	1.6	1.1	0.35
Cadmium	0.6	0.19	0.15
Iron	19,000	13,000	4,900
Lead	15	4.7	26
Manganese	40	12	28
Mercury	0.16	0.17	0.07
Selenium	2.0	3.4	1.3

Estimating Potential Environmental Concentrations

In order to prioritize pollutants for testing, it is necessary to develop estimates of the concentrations in the environment at which pollutants are potentially harmful before field measurements of emissions and environmental concentrations can be conducted at actual operating plants. These estimates of environmental concentrations must be based upon pollutant emission rates, which are themselves estimates.

Estimates of emission concentrations are based on process configurations, coal type and composition, percentage recovery, and fractionation factors, among other parameters. All of these parameters except the fractionation factor are controlled or reasonably well-known. Fractionation factors are characteristic of a given coal but vary among coals. In this study, the fractionation factors used were based on the coal washability tests conducted on numerous coals by the Illinois Geological Survey. Illustrative emission calculations use a simple mass-flow model of a coal cleaning plant and fractionation factors appropriate for the assumed coal; simulation experiments were made both with and without assumed pollution controls.

Only limited efforts were directed to physical transport and dispersion models. The state of the art in this area is quite advanced and the principal problem will be in selecting the model or combination of models to use. Air dispersion and dilution models are well known and readily available. Only simple models of dispersion and dilution in surface water courses may be needed, since most streams receiving coal cleaning plant effluents are so small they can possibly be treated as fully mixed. The areas of greatest uncertainty are leaching and runoff of precipitation through coal storage and coal refuse piles and percolation through the bottoms of tailings ponds. Available simplified approaches to estimating pollutant adsorption and leaching in porous media are expected to be applicable to this general problem.

Ecological transport and distribution previously has been much less well-studied than physical transport and distribution. For this reason, a substantial effort was expended in this study investigating the ecological aspect of the problem. A principal finding of the study is that little is known and much more needs to be learned before predictions can be made with confidence on the ecological transport and fate of potentially hazardous pollutants that might be released by a coal cleaning facility.

Developing Environmental Goals

Documenting and evaluating biological effects ideally should precede setting of standards and development of control technology for coal cleaning facilities. The burden of proof of a need for establishing environmental goals rests with health and ecological effects data; i.e., if no problem exists, there is no need for a solution. Data need to be sound, complete, and rigorous, and they must be interpreted correctly to support environmental goals and recommendations for further development of control devices for coal cleaning facilities. Materials highly toxic to many life stages of many important species during the entire year will require a different level of effort for their control than those mildly toxic to only one unimportant species at a particular time of the year. Unfortunately, the differentiation is not always easy to make. Effects data are not only relatively sparse compared to those needed for adequate assessments but also are typically laboratory results rather than real results from practice. Thus, the following material was developed as another step in providing the necessary feedback for setting standards and for developing control strategies, i.e., which substances need how much control in order to protect health and the environment.

Most biological effects data are obtained in the laboratory and need to be extrapolated to "real world" situations. Extrapolation is the process of inferring or extending a known toxicological response into an unknown area. This extension of knowledge assumes a continuity, similarity, or other parallelism between the two situations. Often biological effects need to be extrapolated from (1) laboratory to field--many differences make this difficult; (2) one species to another--no two species are alike; (3) one medium to another--drinking is not the same as breathing; and (4) one life stage to another--ranges of sensitivity may differ by orders of magnitude. In the present state of the art, biological effects data are collected from a few life stages of a few species for a few routes of entry in a few controlled conditions. On the other hand, the real world situation around a coal cleaning facility contains thousands of species in many stages of growth, all of which may be continuously exposed to various types of doses. Clearly, extrapolation must be done with caution.

Despite the technical difficulties involved in estimating permissible concentrations of toxicants in emission streams, rational approaches are available for dealing with the problem. There are many potentially applicable formulae, some of them developed by or for the U.S. EPA. The formulae have two basic parts: a dose/response part and an adjustments part. The dose/response generally consists of one of the typical laboratory effects measurements: LD_{50}, LC_{50}, and TL_m-96 hr.* Each effects measurement is adjusted by several factors, the argument being that the adjusted dose/response data better conform to the "real world" situation. Adjustments include the following: media conversion (e.g., airborne to waterborne toxicants), safety factors (e.g., 0.01), various types of exposure (e.g., work day to full week), and elimination rate (biological half-life). All the formulae provide estimates of permissible concentrations for single chemicals. All three media (air, water, and land) are considered for both human and nonhuman populations. The multimedia environmental goals (MEG) chart is the principal tool for displaying these quantitative values and represents a major ongoing work supported by the U.S. EPA. The predicted permissible pollutant concentrations are compared against observed environmental concentrations to identify those pollutants whose concentrations exceed the estimated acceptable level.

Decision Criteria for Prioritization

Since all pollutants from coal cleaning processes are not equal in toxicities nor in quantities, there are differing degrees of hazard, and corresponding differences in the relative importance necessary to be placed upon identifying and controlling them.

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* LD_{50}: Lethal dose 50, i.e., the dose of a pollutant required to kill 50 percent of a particular animal species by methods other than inhalation.

LD_{LO}: Lethal dose low, i.e., the lowest dose of a substance introduced in one or more portions by any route other than inhalation over any period of time and reported to have caused death in a particular animal species.

TL_m: Median threshold limit value, i.e., the concentration in water of a pollutant required to kill 50 percent of a particular aquatic species.

All of the parameters making up the total hazard of a pollutant are embodied in the estimated permissible concentration (EPC). However, for many pollutants of known importance, EPC's cannot yet be established.

EPA contractors are developing multimedia environmental goals (MEG) and minimum acute toxicity effluent (MATE) values for an increasing list of pollutants; when this work is complete, a rigorous prioritization of pollutants should be possible--at least into groups of similar hazard. However, because these lists are incomplete, their usefulness is limited.

For the near term, it appears that less rigorous and more pragmatic prioritization criteria may be required to fill the gap. Since the relative importance of controlling a pollutnat can be generally assessed from its acute toxicity and its abundance in coal cleaning processes, criteria are available for their categorization. Also, substances with established criteria or those designated as pollutants should be prioritized. The "Priority 1" pollutants mentioned above were selected using criteria of this type.

A further modifying parameter, for which data are not yet available to implement, is the availability or lack of availability of adequate control technology for pollutants identified as inherently high-risk.

SELECTION OF TEST SITES

A systematic selection of coal cleaning facilities on which field testing and sampling programs could be conducted was necessary in support of the overall environmental assessment of the pollution potential of the various coal cleaning processes. The approach developed has been to select a small number of coal cleaning plants from which data may be obtained. The plants have been selected to represent extremes in variables considered important in evaluating the pollution potential of these types of facilities.

The site selection procedure developed here consists of two steps. The first classifies coal cleaning plants into a number of site categories and identifies a sampling sequence for these categories. The second consists of gathering additional detailed information on specific plants and applying secondary constraints as a means of selecting a single suitable site for sampling within each of the site categories identified by the first step.

In the first step it has been assumed that all sites are equal within each category; in the second step, however, the best or most representative site within a category is to be selected.

The classification of coal cleaning facilities into various site categories has been based on four criteria. These criteria are represented by four variables: (1) acid neutralization potential of the soil surrounding the facility, (2) pyritic sulfur content of run-of-mine (ROM) coal, (3) average annual precipitation, and (4) coal cleaning process technology. Generic types of coal cleaning plants are shown in Table 19 and the definitions of variables and their levels are shown in Table 20. Taking these variables in combinations as extremes, high and low levels for each, there are 16 possible combinations; however, as shown in Table 21, six do not occur for actual sites (e.g., high pyritic sulfur content of ROM coal does not occur in combination with low average annual precipitation).

Recommended Sampling Design

The sequential sampling design for the ten coal cleaning site categories resulting from the site selection procedure is shown in Table 22. The table shows three sampling groups of site categories. The first group to be sampled consists of four site categories: (1111), (1110), (1011), and (0111). Site Category (1111) represents the "worst" case with all four classification variables at high levels of pollution potential. Group 2 would be sampled next and consists of four site categories. Group 3 would be sampled last and consists of two low-rainfall, western site categories. The geographic regions associated with the site categories are shown in the last column as Northern Appalachia (NA), Southern Appalachia (SA), the Midwest (MW), Alabama (A), and the West (W).

The recommended sampling design calls for sites to be sampled in the sequence 1 through 10 as shown in Table 22. On the basis of the statistical rationale described above, the sites within each of the three groups may be sampled in any order. However, on the basis of engineering judgment, Battelle recommends the exact sampling order for each group indicated in Table 22.

TABLE 19. GENERIC TYPES OF COAL PREPARATION PLANTS(36)

<table>
<tr><th rowspan="2">Level(a)</th><th rowspan="2">Plant Type</th><th colspan="3">Coal Size and Unit Operation(b)</th></tr>
<tr><th>Coarse (3 x 3/8 in.)</th><th>Medium (3/8 in. x 28M)</th><th>Fine (28 x 0)</th></tr>
<tr><td>1</td><td>A</td><td>CS</td><td></td><td></td></tr>
<tr><td>2</td><td>B</td><td>CS + J/DMV + MD</td><td></td><td></td></tr>
<tr><td>3</td><td>C</td><td>CS + J/DMV + MD</td><td colspan="2">← AT →</td></tr>
<tr><td>3</td><td>D</td><td>CS + J/DMV + MD</td><td colspan="2">← WT + MD →</td></tr>
<tr><td>3</td><td>E</td><td>CS + J/DMV + MD</td><td>WT + MD</td><td>HC + MD + TD</td></tr>
<tr><td>4</td><td>F</td><td>CS + J/DMV + MD</td><td>WT + MD</td><td>F + MD + TD</td></tr>
<tr><td>4</td><td>G</td><td>CS + J/DMV + MD</td><td>DMC + MD</td><td>HC + MD + TD</td></tr>
<tr><td>4</td><td>I</td><td>CS + J/DMV + MD</td><td>DMC + MD</td><td>F + MD + TD</td></tr>
</table>

(a) Level 1 - Crushing and sizing
Level 2 - Coarse size coal beneficiation
Level 3 - Medium size coal beneficiation
Level 4 - Fine size coal beneficiation

(b) CS - Crushing and sizing devices
J - Jigs
DMV - Dense-medium vessels
DMC - Dense-medium cyclones
AT - Air tables
WT - Wet concentrating tables
HC - Hydrocyclones
F - Froth flotation units
MD - Mechanical dewatering devices
TD - Thermal driers

TABLE 20. CLASSIFICATION VARIABLES AND ASSOCIATED LEVELS USED TO DEFINE SITE CATEGORIES(36)

Variable	Low Level(0)	High Level (1)
N (Neutralization potential)	pH $\geq$ 7.5(a)	pH $\leq$ 6.0(a)
S (Pyritic sulfur)	$\leq$ 1.0%	$\geq$ 2.0%
R (Average annual rainfall)	$\leq$ 15 in/yr	$\geq$ 25 in/yr
T (Coal cleaning process technology)	Plant types A & B(b)	Plant Types F, G, H, & I(b)

(a) pH of soil in the receiving environment. As defined, low N actually refers to a low pollution potential or high soil alkalinity which is, in fact, a high ability to neutralize acid streams.

(b) See Table 19 for definitions of plant types.

TABLE 21. FACTORIAL LISTING OF SITE CATEGORIES(36)

(N,S,R,T)(a)	(N,S,R,T)
(1111)	(0111)
(1110)	(0110)
(1101)(b)	(0101)(b)
(1100)(b)	(0100)(b)
(1011)	(0011)
(1010)	(0010)
(1001)(b)	(0001)
(1000)(b)	(0000)

(a) See Table 20, above, for definitions of low (0) and high (1) levels of pollution potential as expressed by neutralization potential, N; pyritic sulfur, S; average annual rainfall, R; and coal cleaning process technology, T. The combination (1010), for example, denotes a site category with N and R at Level 1 and S and T at Level 0.

(b) These site categories are excluded from further consideration, since no cleaning plants exist with these combinations of variables.

TABLE 22. RECOMMENDED SEQUENTIAL SAMPLING DESIGN FOR COAL CLEANING PLANTS(36)

Group Number	Site Category[a]	Site Characteristics (N, S, R, T)[b]	Regions[c]
1	1	(1111)	NA
	2	(1110)	NA
	3	(1011)	NA
	4	(0111)	MW
2	5	(1010)	NA
	6	(0110)	NA
	7	(0011)	MW, SA, A
	8	(0010)	MW, SA, A
3	9	(0001)	W
	10	(0000)	W

(a) One site from each category is to be sampled in the sequence from 1 through 10, with Site Category 1, defined as (1111), sampled first and Site Category 10, defined as (0000), sampled last. The sampling may be terminated after sampling four site categories (Option C), eight site categories (Option B), or ten site categories (Option A).

(b) See Table 19 for definitions of low (0) and high (1) levels for neutralization potential, N; pyritic sulfur, S; average annual rainfall, R; and coal cleaning process technology, T. The combination (1010), for example, denotes a site category with N and R at Level 1 and S and T at Level 0.

(c) Regions associated with the site categories are denoted as Alabama (A), Northern Appalachian (NA), Southern Appalachian (SA), Midwest (MW), and West (W).

The second step in the site selection procedure requires the choice of individual sites to serve as examples of each generic type of coal cleaning plant identified in the first step.

The selection of sites within each site category was accomplished by imposing a series of constraints to assure that specific kinds of questions are answered about pollution potential and pollution control for the coal cleaning processes. These constraints are grouped in order of importance as being primary, secondary, or tertiary in importance (Table 23).

TABLE 23. FINAL SITE SELECTION PROCEDURES, USE OF PRIORITIZED CONSTRAINTS(36)

Constraints
• Primary
(1) Most efficient pollution control technology
(2) Plant mangement cooperation
• Secondary
(1) Two ages of refuse piles
(2) Greater than mean plant capacity
(3) Baseline data available
• Tertiary
(1) Minimal other coal-related industries in area
(2) Nonmixed refuse piles
(3) Uniform coal source

An initial sorting of the more than 400 known coal cleaning plants listed in the 1977 Keystone Coal Manual(45) produced lists of facilities which correspond to each of the ten site categories. For categories which included a large number of cleaning plants, the secondary constraints were imposed that eliminated plants considered undesirable from a field sampling viewpoint. These abbreviated lists include a total of 47 facilities (Table 24).

TABLE 24. SUMMARY OF POTENTIAL SAMPLING LOCATIONS BY SITE CATEGORY[(a,b)]

Site Category	Site Characteristics (N,S,R,T)	Number of Potential Sites
1	(1111)	3
2	(1110)	6
3	(1011)	11
4	(0111)	2
5	(1010)	3
6	(0110)	4
7	(0011)	8
8	(0010)	4
9	(0001)	3
10	(0000)	3
Total sites to be considered further		47

(a) See Tables 19, 20, and 22 for details on site category and characteristics.
(b) Reference 36.

After the development of the candidate lists for each site category procedures for obtaining cooperation from facility owners and operators were carefully considered. The approach considered best, and having the least potential for initiating a situation which would preclude further contact, was that of having Battelle staff with personal contacts with the specific company make the first approach. This technique was successfully applied. Final or tentative agreement was reached with the first four candidate facilities (Group 1, Table 22) and discussions were underway with several candidates in the next group.

SOURCE TEST PROGRAM

A source test program(38) was designed to facilitate the planning and preparation of site-specific field tests at coal cleaning plants selected for investigation. As such, the source test plan identifies the potential pollution sources associated with a generalized coal cleaning plant and suggests the media likely to be impacted by the effluents from these sources (Figure 3). This information will simplify the process of selecting sampling locations critical to an environmental source assessment of each of the chosen coal cleaning plants and their associated facilities. At the same time, this master plan will ensure that each of the site-specific field tests conforms to the overall EPA program needs and objectives.

Since the site-specific test plans are all parts of a unified data acquisition program, most of the steps involved in planning and executing tests at each facility are the same. Also, many of the sampling locations, techniques, and equipment will be common to most of the site-specific tests (Table 25). A master plan of the common elements to any site test plan expedites the preparation of site-specific test plans by providing a generalized testing framework that can be modified to fit each facility chosen for sampling.

Benefits to Industry

Results of the field testing program will be useful to owners and operators of coal preparation plants even if their facilities are not selected for testing. Field sampling is planned for at least one coal cleaning plant in each of ten site categories. These ten site categories were carefully selected to represent combinations of extremes in the values of four variables. These four variables were also carefully selected to be the ones of major importance in determining the pollution potential of any given coal cleaning plant. Because this site selection design is comprehensive, extrapolation

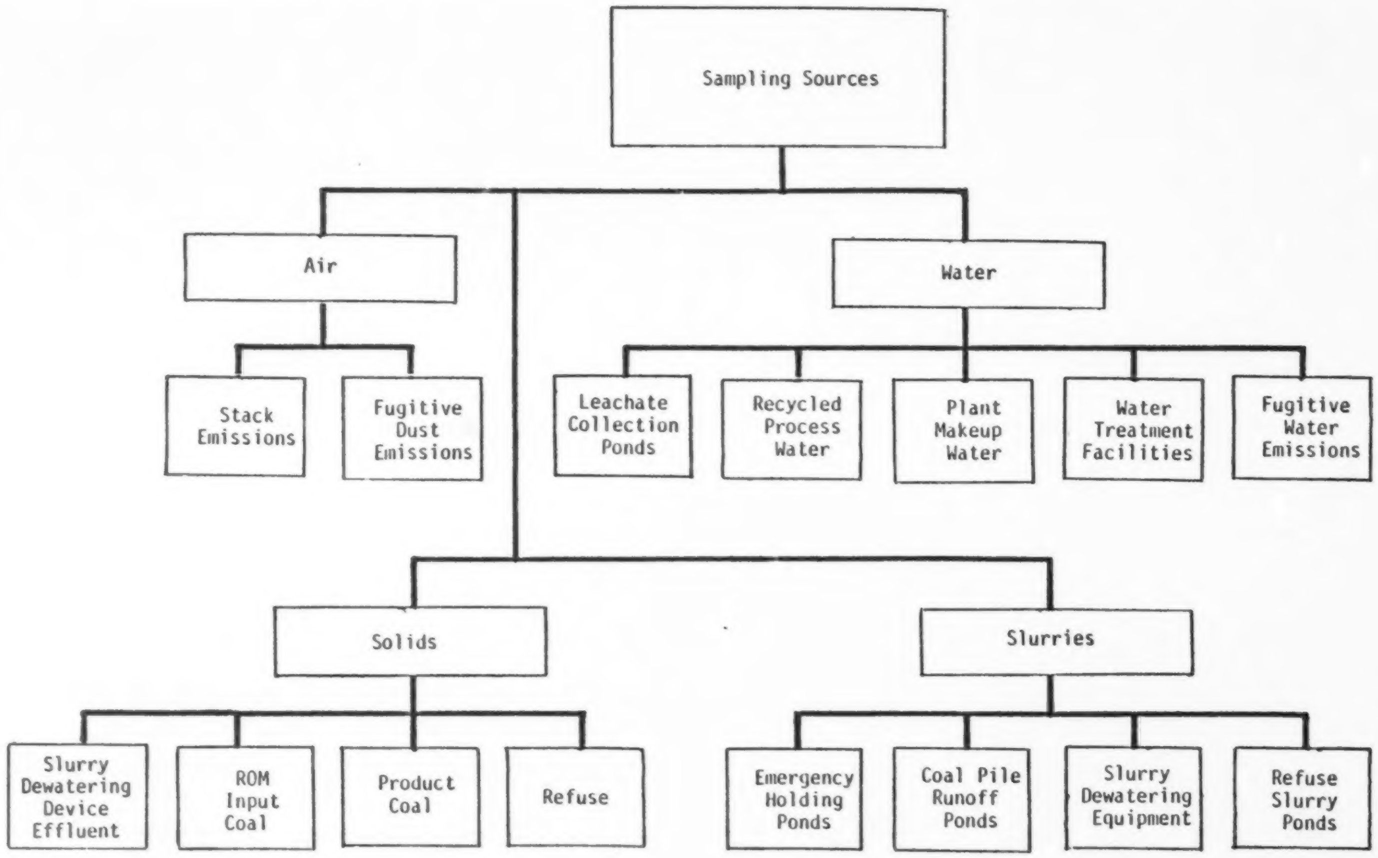

Sampling Sources
Air
Water
Stack Emissions
Fugitive Dust Emissions
Leachate Collection Ponds
Recycled Process Water
Plant Makeup Water
Water Treatment Facilities
Fugitive Water Emissions
Solids
Slurries
Slurry Dewatering Device Effluent
ROM Input Coal
Product Coal
Refuse
Emergency Holding Ponds
Coal Pile Runoff Ponds
Slurry Dewatering Equipment
Refuse Slurry Ponds

FIGURE 3. OVERVIEW OF POTENTIAL SAMPLE TYPES AND THEIR SOURCES AT COAL CLEANING PLANTS(38)

TABLE 25. EXAMPLE OVERALL LEVEL 1 SAMPLING AND ANALYSIS PLAN FOR COAL CLEANING PLANT IN FINAL CONFIGURATION[a,b]

Sampling Locations	Analysis Group(*)
1. Cleaning Plant (overall performance)	
(a) Raw coal (from manual sampler)	C
(b) Unit 1 & 2 product coal (from automatic sampler)	C
(c) Refuse (from freshly dumped refuse)	C
(d) Makeup water from leachate treatment plant (at weir box of treatment plant)	O,W,A,H**
(e) Unit 3 product coal (from automatic sampler)	C
2. 135-ft-diam Thickener ("B" circuit)	
(a) Input slurry (under catwalk over thickener)	S,A
(b) Bottom sludge (from pipe outlet under D & R screens)	S
(c) Clarified water (at weir overflow)	W,O,A
(d) Scum (from scum holding cylinder)	S
3. Emergency Holding Pond	
(a) Surface water leachate (at base of dam)	W,T,H**
(b) Holding pond water	W
(c) Bottom sludge (use Eckman dredge)	S (filter cake only)
4. Cleaning Plant Refuse Disposal Area	
(a) Refuse water leachate (from pipe flowing into leachate holding pond)	W,O,A,T,H
(b) Surface water leachate from leachate holding pond (at base of pond dike)	W,T,H**
(c) Fugitive dust off-site (regular Hi-Vol on Stiles farm)	F
(d) Fugitive dust upwind (using Hi-Vol with Andersen head at leachate water pumphouse)	F
(e) Fugitive dust downwind (using Hi-Vol with Andersen head about 200 yards northeast of disposal area)	F
(f) Fugitive dust downwind (using regular Hi-Vol about 200 yards northeast of disposal area)	F
(g) Refuse dust (use sieved sample of refuse)	T,H,F
5. Treatment Plant for Leachate Water (R&P) Coal Company Property	
(a) Combined coal boney pile leachate and mine water (before treatment)	W

(a) Prepared for Homer City Coal Cleaning Plant Site using methodology developed.

(b) Reference 38.

TABLE 25. (Continued)

Sampling Locations	Analysis Group$^{(*)}$
6. #135 Thermal Dryer Cyclones and Scrubber ("B" Circuit)	
(a) Particulate catch before cyclone/scrubber combination (SASS$^{(***)}$ train)	PC,T,H
(b) Particulate catch after cyclone/scrubber combination (SASS$^{(***)}$ train)	PC,O
(c) Organic catch before cyclone/scrubber combination (XAD-2 resin trap)	O
(d) Organic catch after cyclone/scrubber combination (XAD-2 resin trap)	O
(e) Scrubber slurry (from spigot in pump room)	S
(f) Furnace ash (from ash truck)	C,H,T
7. Coal Stockpile (includes cleaned Unit 1 & 2 product and uncleaned coal	
(a) Surface runoff (input to desilting ponds)	W,A,T,H
(b) Fugitive dust upwind (using regular Hi-Vol at Jim Rudd's laboratory)	F
(c) Fugitive dust downwind (using Hi-Vol with Andersen head north of emergency holding pond)	F
(d) Fugitive dust downwind (using regular Hi-Vol east of emergency holding pond beside abandoned pump house)	F,O
(e) Unit 1 & 2 coal dust (use sieved sample from pile)	T,H,F
(f) Raw coal dust (use sieved sample from automatic sampler)	T,H,F
(g) Unit 3 coal dust (use sieved sample from automatic sampler)	F
8. Coal Pile Desilting Pond No. 2	
(a) Effluent from ponds to IWT (in manhole)	W
(b) Bottom sludge (use Eckman dredge)	S (filter cake only)
(c) Surface leachate from pond (at dike base, if sufficient sample is available)	W
9. Industrial Waste Treatment Plant (IWT)	
(a) Combined influent (under grates in main building)	W
(b) Treated plant effluent (at outlet to common ravine)	W,A
10. Peterson Vacuum Filters ("B" Circuit)	
(a) Common influent (at manifold outlets to trough on one side of unit)	S
(b) Dewatered coal (filter cake taken from side of screen)	C
(c) Water filtered from slurry (at overflow box)	W

TABLE 25. (Continued)

Sampling Locations	Analysis Group(*)
11. Bird Solid Bowl Centrifuge ("B" circuit on refuse stream)	
(a) Combined influent (inlet junction box located one floor above)	S
(b) Dewatered refuse (use long handled scoop to catch before dropping into refuse bin)	C
(c) Water effluent (install port on side of pipe located one floor below Bird)	W,A
12. Truck Dump (for trucked-in raw coal)	
(a) Hi-Vol at truck dump grate	F
13. Background Dust Location	
(a) Regular Hi-Vol on adjacent farm (southwest of power complex)	F
14. Enviro-clear Thickener ("B" circuit)	
(a) Slurry input (from deaeration flume)	S
(b) Clarified water (install sampling port in pipe)	W
(c) Dewatered underflow (from box north of thickener)	S

* A = aquatic tests; T = terrestrial (microcosm) test; H = human health tests; C = coal analysis; F = fugitive dust analysis; O = organic analysis; PC = particulate catch; S = slurry analysis (includes both coal and water quality analyses); W = water quality analysis.

** Human health test series will not include rabbit alveolar macrophage test.

*** SASS = Source Assessment Sampling System developed by EPA.

of test results to a large number of coal cleaning plants should be possible. Therefore, benefits to this expanded group of coal cleaning plants will include the following:

- Reduced costs for pollution control. Cost reductions should be possible by utilizing the following field program results:
    - Information needed to select the most efficient pollution control device or technique for a specific type of effluent stream in a specific environmental setting
    - Information needed to select the process equipment and set points that result in effluent streams with reduced pollution potential.
- Decreased pollutant monitoring and reporting requirements. A better understanding of the pollutants of concern in specific effluent streams should reduce the number of air and water quality parameters and/or effluent streams that are under consideration for government regulation.
- Improved pollution control technology. Identification of the most toxic waste streams should stimulate research and development on improved control technology techniques.

Test Execution

The site-specific test plan (Figure 4) will be generated after the respective sites have been selected. Each plan will be an application of the Master Test Plan to the particular circumstances of a specific site. Very specific sampling information will be included; e.g., schedules, costs, precise sampling station locations, and number of samples. Each site-specific plan will depend heavily on information gleaned from the site selection plant visit and a pretesting site visit.

The phased approach to environmental assessment will be used in the test design. All plants in the test program will be tested using a modified Level 1 technique; i.e., Level 1 information will be obtained either through Level 1 testing or through acquisition of existing environmental data. The funds remaining after the Level 1 tests have been completed will determine the amount of follow-up Level 2 testing which can be performed on important streams identified by the Level 1 testing.

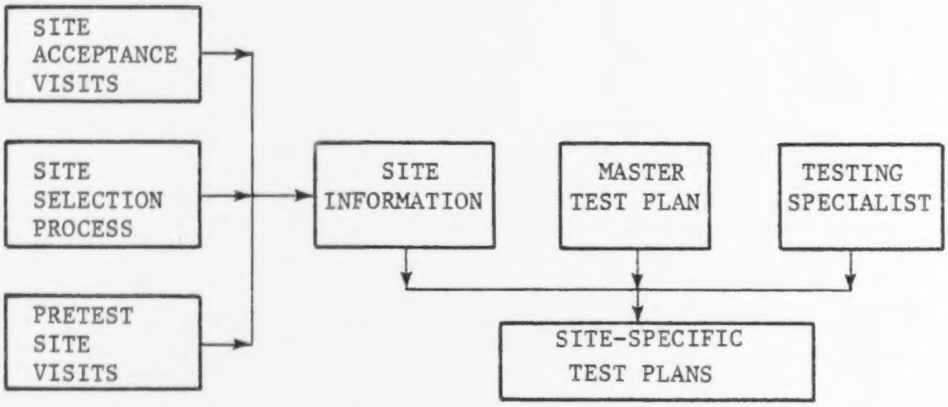

SITE ACCEPTANCE VISITS
SITE SELECTION PROCESS
PRETEST SITE VISITS
SITE INFORMATION
MASTER TEST PLAN
TESTING SPECIALIST
SITE-SPECIFIC TEST PLANS

FIGURE 4. TEST PLAN DEVELOPMENT--SITE-SPECIFIC PLANS(38)

The actual testing will be performed as closely as possible in conformance with the site test plans. The sections below briefly describe the test methods to be used; these are summarized in Table 26.

Fugitive Emissions Sampling

The three common methods used for sampling fugitive emissions are known as quasi-stack sampling, roof monitoring, and upwind/downwind sampling. In quasi-stack sampling, a temporary hood is installed to divert the emissions to an exhaust duct or stack of known cross-sectional area. Emissions are then measured using conventional stack sampling methods and total emissions are calculated. Emissions from material-handling operations such as belt conveyance and loading are sometimes amenable to measurement by this method.

Roof monitoring will be used for sampling fugitive emissions entering the ambient air from building or other enclosure openings, such as doors and windows, which are too numerous to permit the installation of temporary hoods. Such sampling generally is limited to a mixture of all uncontrolled emissions within the enclosed structure.

Upwind/downwind sampling will be employed to measure fugitive emissions from nonpoint sources that cannot be hooded and are not enclosed in a structure that will permit the use of the roof monitoring method. Sources include material handling and storage operations and disposal dumps. The upwind/downwind method samples air entering a source (upwind) and leaving a source (downwind). The specific dust sources will be identified by morphological examination of filter pads. Most airborne pollutants can be measured by the upwind/downwind method. This method is sensitive to meteorological conditions, such as wind speed, wind direction, humidity, and ground moisture. The settling rates of the larger particles require that the sampling strategy be designed to insure that representative particles are collected. The upwind/downwind is the most frequently used method to monitor fugitive dust emissions. Potential generic sampling locations are indicated in Figure 5.

TABLE 26. SUMMARY OF TEST METHODS(38)

- AIR
  - Fugitive Emissions Sampling (quasi-stack sampling, roof monitoring, or upwind/downwind sampling)
  - Noise
- WATER
  - Process water
  - Coal and refuse pile runoff and leachate
  - Groundwater
  - Receiving streams
- BIOASSAYS
  - Gaseous grab samples (plant stress ethylene test)
  - Liquid wastes (aquatic toxicity tests)

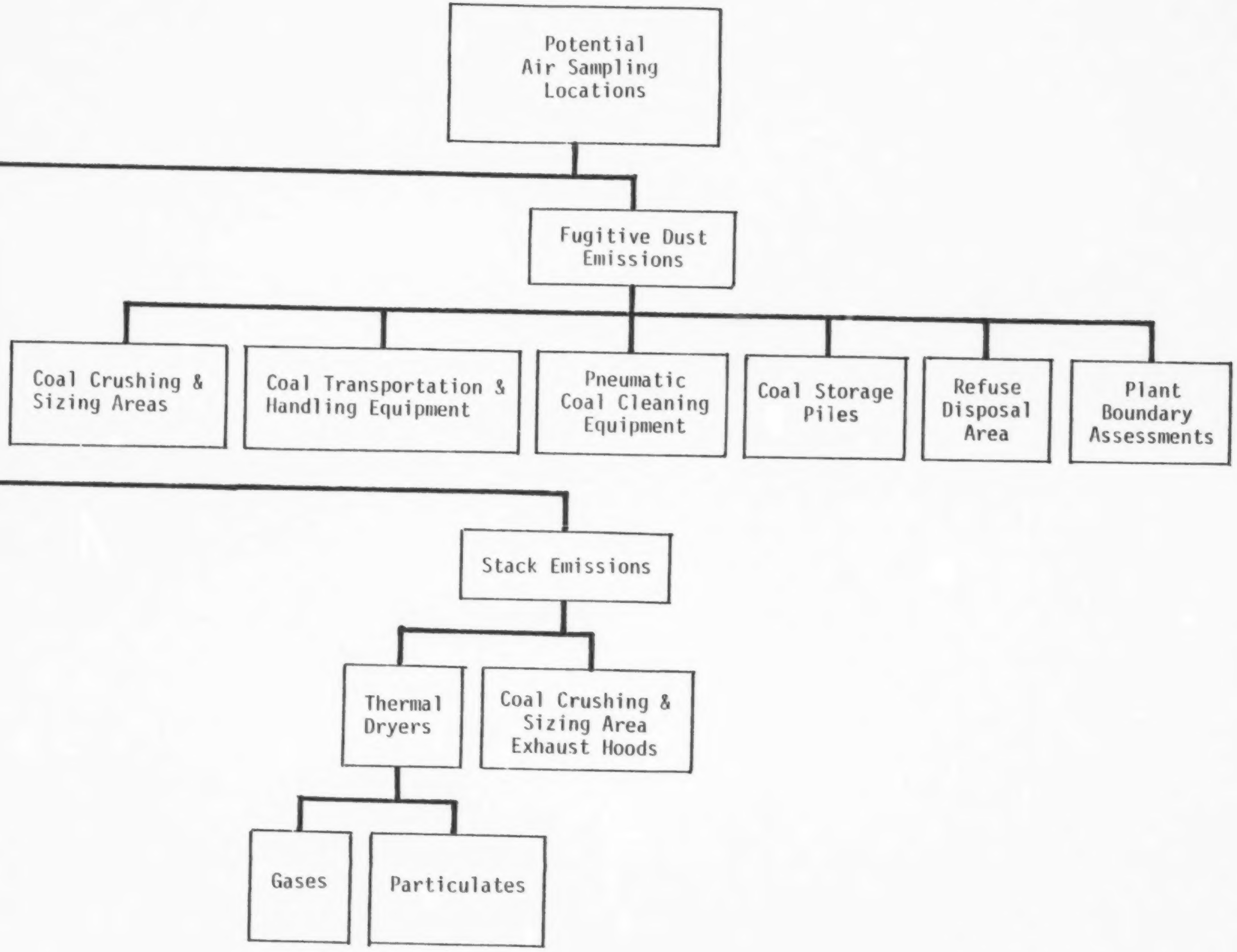

Potential Air Sampling Locations
Fugitive Dust Emissions
Coal Crushing & Sizing Areas
Coal Transportation & Handling Equipment
Pneumatic Coal Cleaning Equipment
Coal Storage Piles
Refuse Disposal Area
Plant Boundary Assessments
Stack Emissions
Thermal Dryers
Coal Crushing & Sizing Area Exhaust Hoods
Gases
Particulates

FIGURE 5. POTENTIAL AIR SAMPLING LOCATIONS (38)

Water Sampling

Process water, coal and refuse pile runoff and leachate, and groundwater will be sampled at appropriate places (Figures 6 and 7). Each time a station is sampled, several separate containers will be filled with the water, for analysis of a number of parameters. The temperatures, pH, conductivity and dissolved oxygen content of the water will be measured in the stream at the time of sampling. The samples will be preserved in the laboratory by methods that are specific to the particular parameters being studied, and the particular analytical methods to be used.

Water sampling stations will be chosen to provide samples upstream and downstream from the points at which effluents are released to receiving streams. This will include process water samples upstream and downstream of pollution control systems, samples upstream and downstream of the points where coal and refuse pile leachate and runoff drains empty into a receiving stream, and groundwater samples from wells up-gradient and down-gradient of refuse disposal area. The sampling of solid wastes of the process is a necessary input to evaluation of potential runoff and leachate transfer to aquatic systems (Figure 8).

Bioassays

The toxicity of emissions will be determined by bioassays conducted according to Level 1 procedures(46). Possible toxicity of gaseous discharges will be determined by observing the ethylene produced by soybeans in response to exposure to the effluent gases. Liquid waste toxicity will be assessed by exposing fatheat minnows, daphnia, and algae to stream samples.

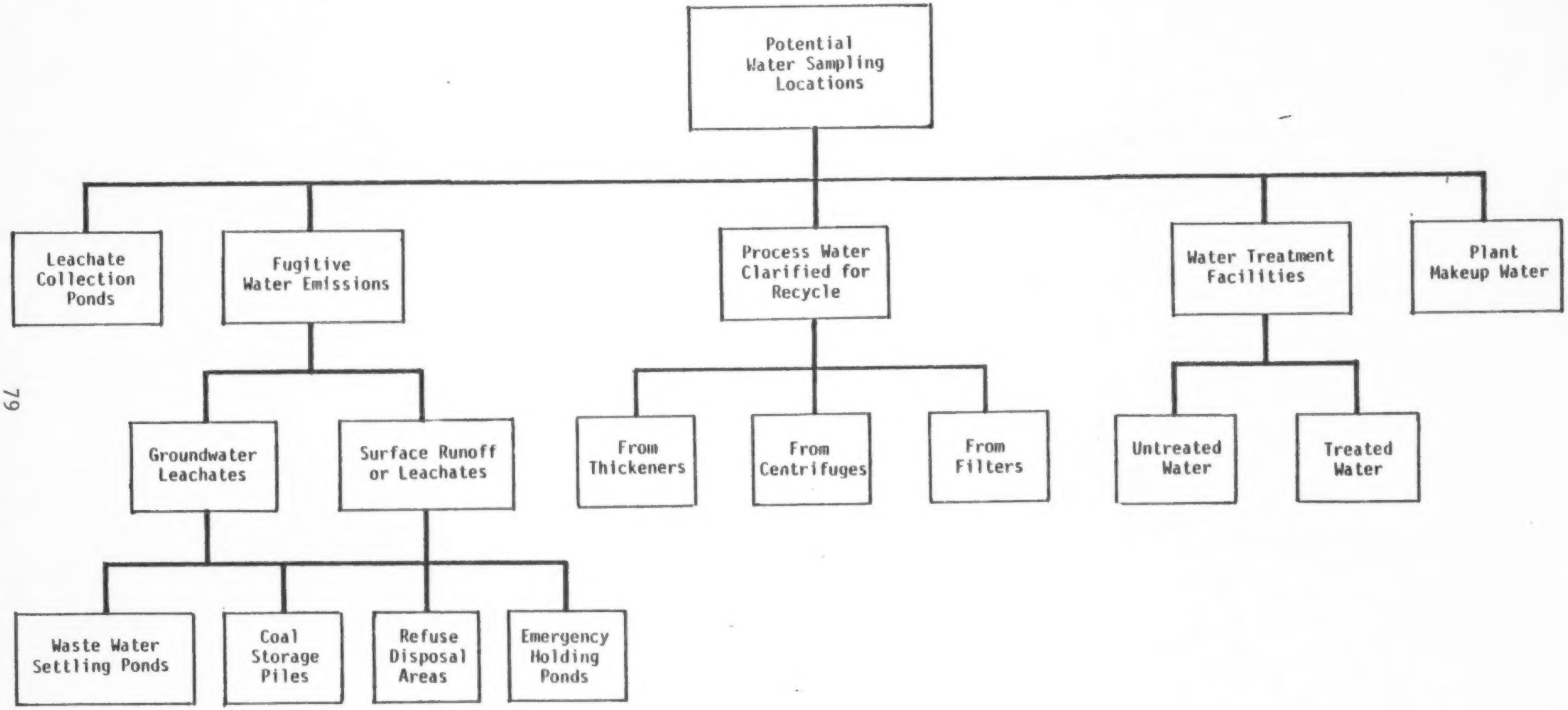

Potential Water Sampling Locations
Leachate Collection Ponds
Fugitive Water Emissions
Process Water Clarified for Recycle
Water Treatment Facilities
Plant Makeup Water
Groundwater Leachates
Surface Runoff or Leachates
From Thickeners
From Centrifuges
From Filters
Untreated Water
Treated Water
Waste Water Settling Ponds
Coal Storage Piles
Refuse Disposal Areas
Emergency Holding Ponds

FIGURE 6. POTENTIAL WATER SAMPLING LOCATIONS (38)

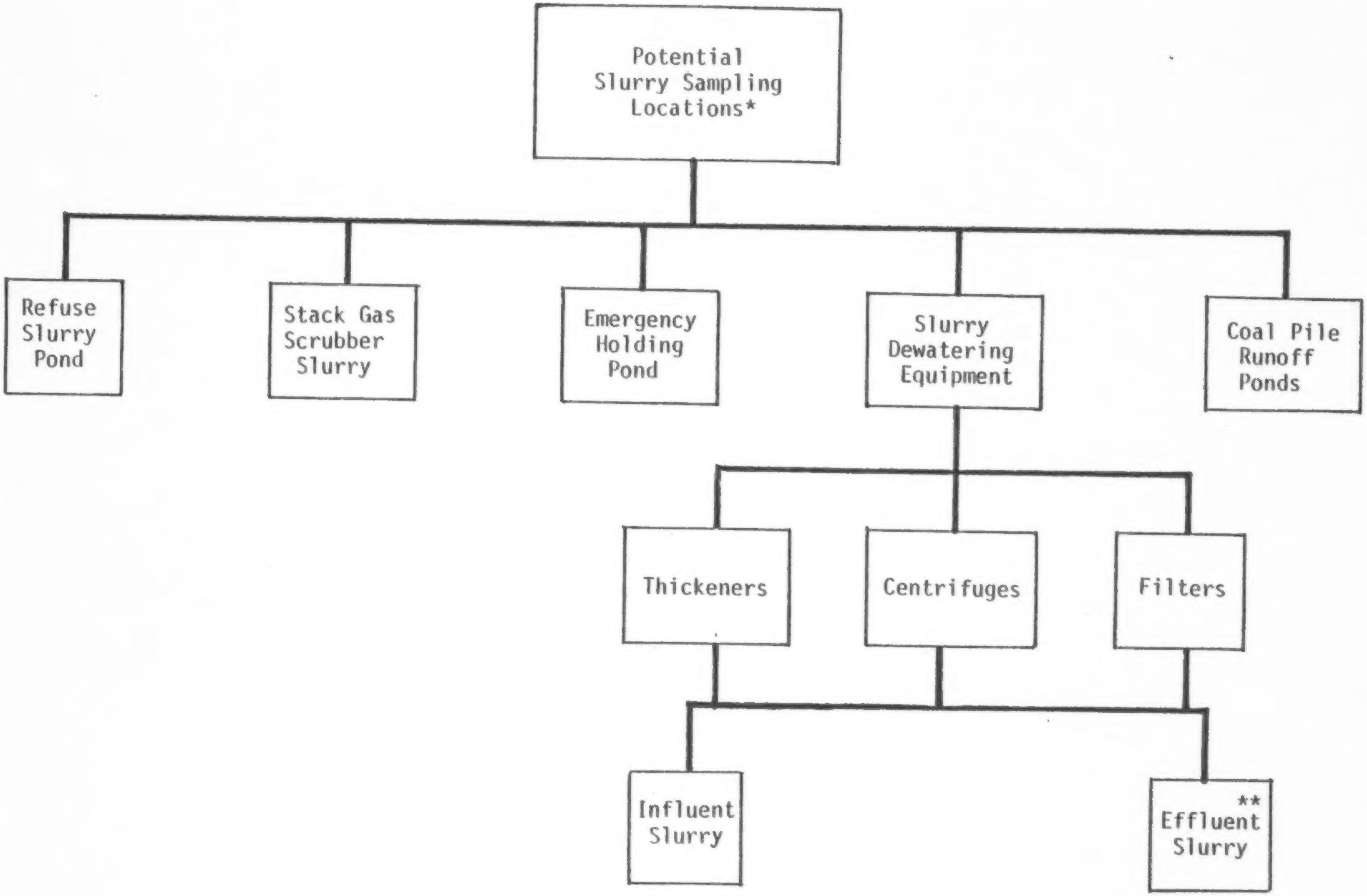

Potential Slurry Sampling Locations*
Refuse Slurry Pond
Stack Gas Scrubber Slurry
Emergency Holding Pond
Slurry Dewatering Equipment
Coal Pile Runoff Ponds
Thickeners
Centrifuges
Filters
Influent Slurry
** Effluent Slurry

FIGURE 7. POTENTIAL SLURRY SAMPLING LOCATIONS (38)

*Slurry samples will be filtered so that the water and solids can be analyzed separately.

**In some cases the effluent may be a solid.

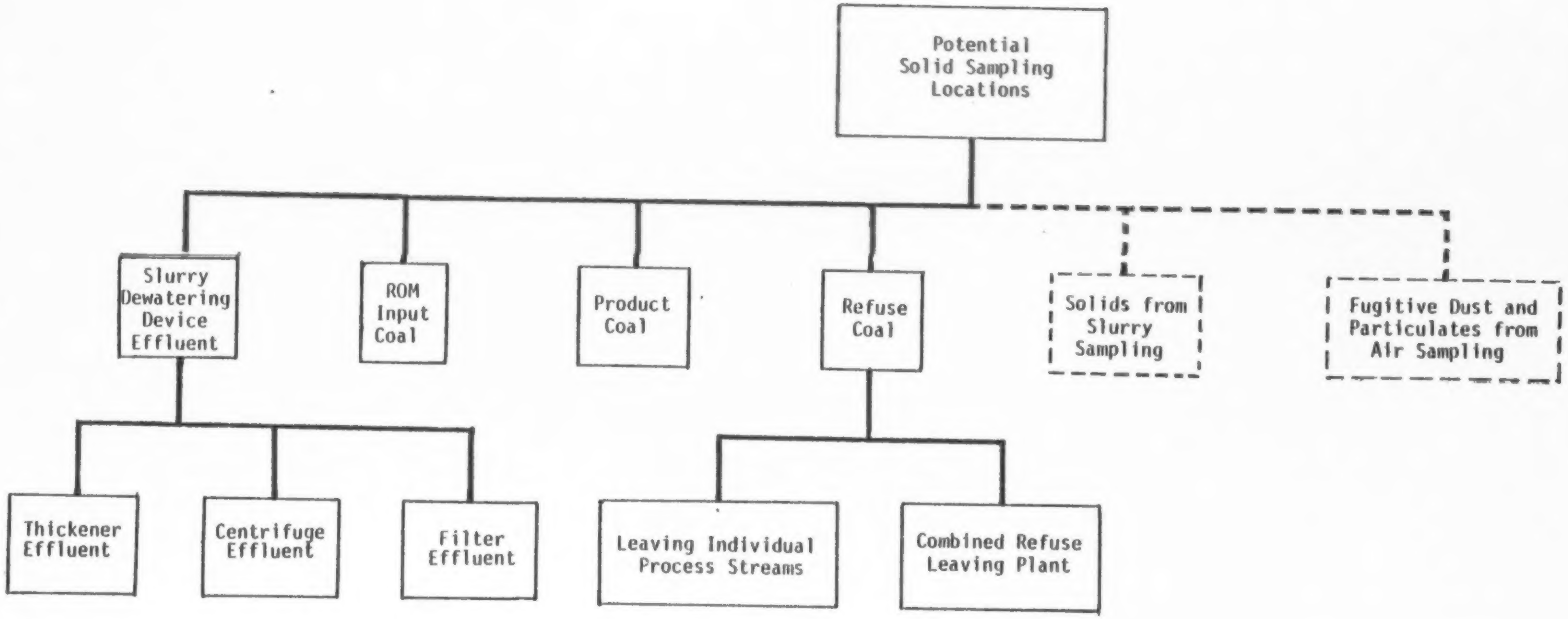

Potential Solid Sampling Locations
Slurry Dewatering Device Effluent
ROM Input Coal
Product Coal
Refuse Coal
Solids from Slurry Sampling
Fugitive Dust and Particulates from Air Sampling
Thickener Effluent
Centrifuge Effluent
Filter Effluent
Leaving Individual Process Streams
Combined Refuse Leaving Plant

FIGURE 8. POTENTIAL SOLID SAMPLING LOCATIONS(38)

Use of Test Results

The results of the testing program are expected to provide expanded information in areas where little or no information is currently available in the literature. For this use of the results, the performance data on pollution control systems and the data on actual pollutant concentrations should be the most important contribution. This information will facilitate comparison of pollution control systems operating on a variety of effluent streams.

The environmental effects data will be useful primarily in conducting studies of the relative environmental impacts of coal cleaning and usage of uncleaned coal (trade-off studies).

HOMER CITY TESTING PROGRAM

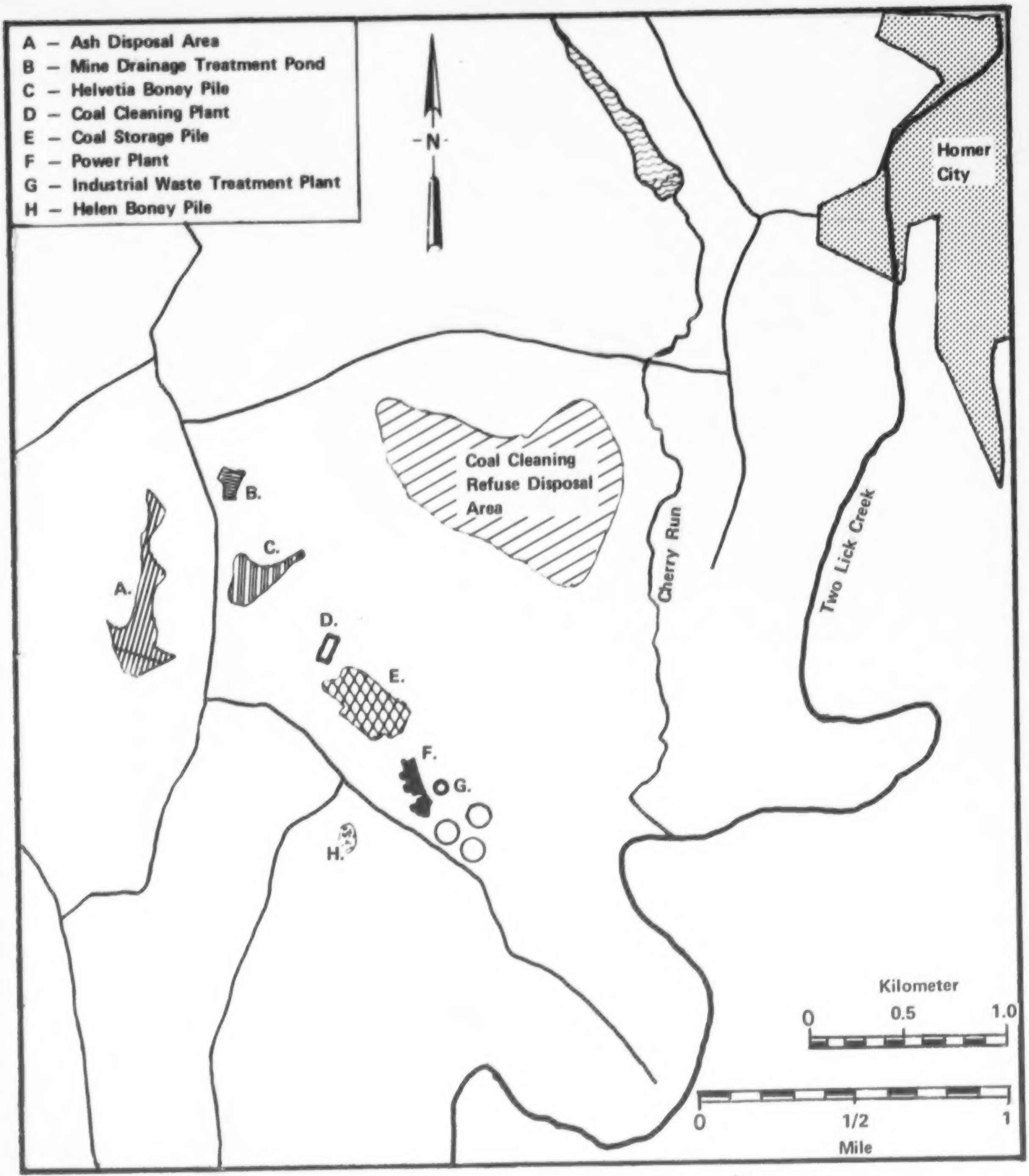
The advanced coal cleaning facility at the Homer City generating station near Homer City, Pennsylvania, has been chosen as a site for field testing. This facility represents the group of cleaning plants (site category 1) that processes ROM coal with high pyritic sulfur (≥ 2 percent) content, uses high technology coal cleaning processes, and operated in an environment with high rainfall (≥25 in/hr) and low soil neutralization ptoential (pH ≤ 6.0).

Prior to the Level 1 program, an environmental monitoring program was conducted in the vicinity of the Homer City complex.(40) It was conducted within a study area that can be approximately bounded by a circle 4 miles (6.4 km) in diameter. The advanced coal cleaning plant in the center of the study area is about 2 miles (3.2 km) southwest of Homer City, Pennsylvania. Two of the aquatic biota sampling stations were slightly outside of the circular study area.

The six major habitat types within the study area are hardwood forest, coniferous forest, cropland, grassland, water bodies, and areas of industrial development. The forest areas are primarily hardwoods, dominated by oak and hickory. Isolated pockets of pine are present as plantations rather than naturally occurring species. Cropland is extensive in the study area, including contour and strip-cropped fields of corn, wheat, and hay. Grasslands include those areas that are presently grazed and those areas that were previously grazed or farmed and are now in a transition stage toward becoming a forest.

Stream water quality evaluated within the study area is affected by a number of land uses which are either included in the immediate study area or take place at locations farther upstream. The five major land uses affecting stream water are: agriculture, mining, urbanization, construction, and power generation. Agricultural runoff is a problem because of the hilly terrain and includes runoff from both farmland and pastures. Many upstream watersheds add acid mine drainage from abandoned or active strip mines. Almost the entire study area is on top of deep mines. As indicated earlier, Homer City, Pennsylvania, is immediately adjacent to the study area on the northeast, and Indiana, Pennsylvania, is only 5 miles (8.0 km) north of Homer City. Both towns directly or indirectly add effluents from industrial and sewage treatment facilities to Two Lick Creek before it flows through the study area. During Battelle's sampling campaigns, both the coal cleaning plant and the refuse disposal area for that facility were under construction in the study area. Finally, the study area includes the Homer City Power Station, with its associated coal storage, water treatment, and waste disposal facilities.

The Homer City Station is one part of an integrated power complex which includes two deep coal mines; coal cleaning, storage, and transport facilities; power generation facilities; and waste disposal and treatment facilities (Figure 9). Some coal used at the Homer City Station comes from the two dedicated deep mines in the power complex; other coal is hauled by truck from other mines. Solid refuse from power complex activities is deposited in three different types of disposal areas, including an ash disposal area, mine waste or "boney" piles, and the cleaning plant refuse disposal area. Liquid waste treatment facilities in the power complex include: mine and boney pile leachate water treatment facilities, an emergency holding pond constructed near the coal cleaning plant, coal storage pile runoff desilting ponds, an industrial waste treatment plant, power plant storm runoff desilting



A – Ash Disposal Area
B – Mine Drainage Treatment Pond
C – Helvetia Boney Pile
D – Coal Cleaning Plant
E – Coal Storage Pile
F – Power Plant
G – Industrial Waste Treatment Plant
H – Helen Boney Pile
N
Homer City
Coal Cleaning Refuse Disposal Area
Cherry Run
Two Lick Creek
A.
B.
C.
D.
E.
F.
G.
H.
Kilometer
0
0.5
1.0
0
1/2
1
Mile

FIGURE 9. MAP OF THE HOMER CITY POWER COMPLEX

ponds, bottom ash sluice water desilting ponds, sewage treatment facilities, and ash disposal area leachate treatment ponds.

A series of multimedia grab-sampling campaigns were conducted in the study area to document the abundance or concentration of selected environmental parameters. The data collected in the campaigns were used to evaluate the air, water, and biological quality of the study area both through interpretive techniques and by direct comparison with EPA Multimedia Environmental Goals (MEG) values.

Fugitive dust was monitored using high-volume samplers at locations verified by a multiple source fugitive dust dispersion model, field-calibrated to the monitoring results and source conditions at the Homer City Station. The model is able to predict dispersion levels at various distances under a variety of meteorologic conditions.

The fugitive dust chemical analysis revealed that there are uncombusted coal dusts 2,000 meters downwind of the coal cleaning plant site that exhibit levels of lead, cadmium, arsenic, and mercury higher than those present in the whole-coal or disposed ash. Cadmium and lead values are several orders of magnitude higher than those in the whole-coal or disposed ash. Beryllium and vanadium were not found in the coal dusts but are quite evident in the source coals. Magnification of trace metal compounds may be attributed to the cleavage of the coal along planes where these metal compounds were concentrated. The particles released by fracturing along these planes evidently tend to become airborne due to air or vehicular movement over the coal pile.

Water quality in each of the basins monitored is a direct reflection of the types of land uses involved. The five major land uses in the study area affecting stream water are: agriculture, mining, urban, construction, and power generation.

The stream sediments of the study area are heavily laden with metal compounds. These streams exhibit high dissolved oxygen levels and, were it not for the pH extremes and suspended solid levels, the streams could begin a rather rapid recovery. As expected in a coal region lithology, the streams had sufficiently high levels of various forms of iron, manganese, sulfur, and calcium to be of some concern.

The aquatic biota reconnaissance involved the sampling of three groups of organisms (attached algae, bottom-dwelling invertebrates, and fish) indicative of the streams' biological quality. Sampling was conducted at 14 locations in eight streams.

The subjective analysis of water quality based on the aquatic biota observed was in close agreement with the water chemistry analysis.

The terrestrial habitats evaluated within a 2-mile (3.2-km) radius of the coal cleaning plant are quite diverse and support animals common to all successional stages, especially those wildlife species associated with the early successional vegetation. Very little wetland habitat exists, and the streams and ponds which do occur in the area are unsuitable for water birds. The observation of particulate matter covering vegetation and leaf litter within 1 mile (1.6 km) of the coal pile suggests that plant biota in that area may soon begin to show signs of stress.

In summary, the ambient environment in the study area appeared to be typical of many western Pennsylvania areas which include coal mining and handling operations. In many cases, stream water chemistry and biological quality were adversely affected by pollution sources outside of the study area, especially by acid mine drainage. Power complex operations had a negative impact on the chemical and biological quality of a few of the smaller tributaries. Levels of particulates in the air were high in the vicinity of the coal storage pile, but dropped down to relatively good air quality levels off of the power station property. Terrestrial vegetation is presently diverse in the study area. Some of the more sensitive plant species close to the coal pile, however, may begin to show signs of stress due to the accumulation of coal dust and other particulates.

Data Comparison with MEG Values

Preoperational monitoring data from the Homer City study area were compared with the values listed in the Multimedia Environmental Goals (MEG) documents prepared for the U.S. EPA by Research Triangle Institute(47,48). MEG values represent estimates of the maximum levels of significant contaminants which are not considered to be hazardous to man or the environment. The MEG methodology was developed to facilitate the evaluation and ranking of pollutants for the purpose of environmental assessment of energy-related processes. MEG values have been estimated for 216 pollutants by extrapolating various toxicity data by means of simple models. For most of these pollutants, maximum values have been estimated for each of the three media (air, water, and land). For each of the three media, separate maximum levels have been estimated which are not considered to be hazardous to (1) human health and (2) entire ecosystems.

The MEG values that are particularly appropriate for comparison with the environmental monitoring data from the study area are those designated as estimated permissible concentrations (EPC's). EPC's are the maximum concentration of a pollutant which presents no hazard to man or biota on a continuous long-term basis. These EPC values are considered acceptable in the ambient air, water, or soil, and do not apply to undiluted effluent streams. The ambient application of EPC's corresponds to the ambient type of sampling conducted prior to operation of the Homer City Coal Cleaning Plant.

A second type of MEG values considered in this study are those designated as minimum acute toxicity effluent (MATE) values. MATE's are to be compared with concentrations of pollutants in undiluted effluent streams and are applicable to exposure for short time periods. Although none of the preoperational monitoring near Homer City involved undiluted effluents, in the case of a few pollutants, the MATE value was the only MEG value available for comparison with the field data. As an example of the comparisons made, Table 27 shows comparisons of Homer City surface water quality data with EPC and MATE values for water environments.

TABLE 27. COMPARISONS OF EPC AND MATE VALUES FOR WATER WITH HOMER CITY SURFACE WATER QUALITY DATA(a)(40)

MEG Category and Substance	Minimum Acute Toxicity Effluent (MATE) for Ecology	Estimated Permissible Concentration (EPC) for Ecology	Streams in the Vicinity of Homer City Station: Cherry Run: Main Stem		North Tributary to Cherry Run		South Tributary to Cherry Run: Upstream		South Tributary to Cherry Run: Downstream		Wier's Run Below Ash Disposal Area		Tributary to Wier's Run		Hager's Pond Tributary		Common Ravine		Two Lick Creek		Reference Stream Dec-Apr Average(e)
			Water Quality Evaluation(b)																		
			Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
18 Phenolics	500	100(d)	--(c)	--	--	--	--	--	--	--	10	ND	7	6	340	9	360	30	8	ND	--
32 Beryllium	55	11(d)	ND(f)	ND	ND	ND	ND	ND	ND	ND	ND	ND	--	--	20	20	ND	ND	ND	ND	--
34 Calcium	16,000	--	23,600	16,500	20,300	17,400	38,900	19,200	37,200	7,200	208,500	86,000	--	--	209,000	113,000	485,000	102,500	43,900	21,000	3,500
46 Lead	50	10(b)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	30	20	ND	ND	1
47 Ammonia Nitrogen	50	10(d)	80	<50	60	<50	50	<50	<50	<50	630	180	--	--	14,400	360	4,200	1,600	1,280	190	--
49 Arsenic	50	10(d)	ND	ND	ND	ND	ND	ND	ND	ND	8	ND	ND	ND	20	ND	60	20	ND	ND	<1
65 Vanadium	150	75(d)	ND	ND	ND	ND	300	ND	ND	ND	ND	ND	--	--	ND	ND	ND	ND	ND	ND	--
68 Chromium	250	50(d)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	40	20	ND	ND	<10
68 Chromium+6	250	50(d)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	ND	ND	--
71 Manganese	100	20(d)	460	20	280	20	210	130	1,400	<20	6,100	1,400	--	--	45,200	2,210	1,760	680	1,300	550	20
76 Nickel	10	2(d)	ND	ND	ND	ND	ND	ND	ND	ND	100	70	ND	ND	640	80	140	60	ND	ND	--
78 Copper	50	10(d)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	60	ND	50	30	ND	ND	0
81 Zinc	100	20(d)	20	ND	20	20	50	50	50	30	120	90	40	ND	1,730	100	290	230	110	80	0
82 Cadmium	1	0.4(d)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2	ND	3	2	ND	ND	0
83 Mercury	250	50(d)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<0.5
			Biological Quality Evaluation(g)																		
Attached Algae			F		F		F		P		F		G		P		P		P		
Bottom-Dwelling Invertebrates			P		G		G		P		P		G		P		P		P		
Fish			F		G		G		P		P		G		P		P		P		
Overall Rating			F		G		G		P		P		G		P		P		P		

(a) All values are given in ug/ℓ; EPC and MATE values are from Cleland and Kingsbury(47,48).
(b) Data from three sampling campaigns conducted by Battelle in the study area.
(c) Data not available.
(d) Based on most stringent existing or proposed Federal standard for water quality (Cleland and Kingsbury, 1977a and b).
(e) Chemical analysis during water year 1973 of Young Women's Creek near Renovo, Pennsylvania (U.S. Department of the Interior, 1974).
(f) ND = not detectable.
(g) The aquatic biota evaluations are based on standing crop, species diversity, and presence of indicator species or families; G = good; F = fair; and P = poor aquatic biota quality. Data are from two sampling campaigns conducted by Battelle in the study area.

Note: For ease of making comparisons, EPC and MATE values which are used for making comparisons and the field data which exceed them are underlined.

MODELING AND INFORMATION SYSTEMS*

While physical cleaning of coal has been a routine process for many years, computer models and information systems designed to assist in the evaluation of alternatives had only begun to be developed. During the course of this contract, a number of contributions were made to advance the state-of-the-art knowledge of coal cleaning by providing fast, sophisticated, useable methods for the evaluation of various design and costing parameters, and through increasing the accessibility of information to potential users.

Most important among the several developments are:

- Modification of CPSM4 (Coal Preparation Simulation Model, Version 4). This modification vastly improved the algorithm efficiency, allowed actual facility modeling, and made the program more universally usable.
- Development of RPAM (Reserve Process Assessment Model). The model allows the simultaneous investigation of U.S. coal reserve base, sample washability data, and 50,000 detailed coal analyses.
- CCIC Development and Operation (Coal Cleaning Information Center). CCIC provides on-line access to reference materials of over 1400 documents. Periodic lists of new materials and a user's guide were also prepared.

COMPUTER MODEL FOR EVALUATING PROCESS TECHNOLOGY

During the course of this program, an original computer program based upon the U.S. Bureau of Mines Coal Preparation Simulation Model, Version 4

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* Content supported by Battelle reports: "Coal Preparation Plant Computer Model Users Handbook"(49); "The Use of Coal Cleaning for Compliance with SO_2 Emission Regulations"(10); and "On-Line User Guide for CCIC"(50).

(CPSM4) was modified.(49) That program has been modified and its applicability to physical coal cleaning improved in the following five aspects.

1. The core requirements have been reduced and the modeling algorithms simplified and unified.
2. A notation for specifying coal cleaning configurations has been developed.
3. Conventions have been introduced to make possible the simulation of actual coal cleaning facilities, as opposed to generalized ones.
4. The maximum number of flows and units accepted by the program has been increased significantly.
5. The program has been written so that it can run on a variety of computers and has been implemented at numerous sites.

Program CPSM4 is designed to simulate certain aspects of the performance of a coal preparation plant. Generically, it is a steady-state process modeling system. The term process refers to the fact that CPSM4 views a coal preparation plant as consisting of a set of components, or units of equipment interconnected via a set of flows of coal which they manipulate. The term steady-state refers to the assumption made within time. The formalization of a coal preparation plant as a process is ideal. The steady-state assumption is clearly a simplifying one.

The use of program CPSM4 requires three types of information: first, a float-sink type specific gravity analysis of the coal to be processed; second, a configuration showing the units of equipment as they are to be applied to the coal; and third, an equipment inventory describing the performance of each equipment type relative to the unit operations. The program will then produce an analysis of the performance of each unit of equipment, a specific gravity analysis of each output flow from each unit, a summary of the unit performances, and a summary of the flow characteristics. In addition to the above, the program had been used to model the Homer City coal cleaning plant and has reproduced closely the design material balance for that plant.

Each of these five modifications made to the program was, of course, accomplished in such a manner that the transportability of the program was fully maintained.

The first set of modifications allows the program to model the flow of water through the configuration as well as the flow of solids. This capability allows the user to calculate the water balance for a configuration. This is a difficult calculation to perform by hand. Mathematically, this modification involved specifying equations for simulating various levels of moisture in the output flows of units and designing an iterative procedure for balancing the water flows into and out of a configuration.

The second set of modifications was made possible by the above. These modifications involve simulating the behavior of dewatering unit operations. These operations were completely ignored in the original version of the program since that version was unable to deal with water flows. The particular aspect of dewatering devices, other than their treatment of water flows, which made them difficult to model, was the size degradation caused by them. Dewatering devices tend to cause changes in the size distribution of the solids passing through them. To deal with this resizing phenomenon, a prebreakage algorithm was added to the system. This algorithm uses the same basic functional form as was used already by the crusher and rotary breaker unit operations. This prebreakage algorithm is not only usable to simulate the size degradation behavior of dewatering devices, but also of other devices such as washers.

The third set of modifications expanded the flow stream description so that the movement of any element, not just Btu's, sulfur, and ash, could be traced through the coal cleaning facility. This enhancement will greatly simplify the description of trace element movement through the configurations.

The fourth modification consisted of adding a data base capability to the program. Via this capability flow stream descriptions and configurations may be stored on and retrieved from direct access files. This capability greatly simplifies the use of the program, especially when many different feeds are being applied to a given configuration or vice versa.

The fifth modification involved adding a cost component to the program. Using this component, the analyst can instruct the program to accumulate the individual capital and operating cost elements into a time series description of the required cash flows by type. Based on this cash flow description, the program then calculates the selling price required for the output of the configuration in order to achieve a specified rate-of-return on investment.

The major limitation of the work done to date, and the major area where additional work is needed, has to do with the testing of the simulation results against actual coal cleaning configuration behavior. Although some work has been done in this area with the Homer City plant, as mentioned above, more information is needed. The area which is weakest in this regard is the data for component costs. The program presently contains algorithms which should be able to accurately simulate coal cleaning configuration behavior; however, the coefficients for those algorithms are at this point very approximate. Additional cost and performance data are needed before this deficiency can be corrected.

A detailed documentation of the model, including these modifications, has been prepared. The final modification, a User Handbook and Program Documentation Guide(49), describes user preparation of input for the program, the mathematical operations which the program performs on those inputs, and the meanings of the resultant outputs.

RESERVE PROCESSING ASSESSMENT MODEL

As there are many different combinations of coal cleaning operations which may be employed, it was apparent that an improved method for assessing the cleanability of the nation's coal reserves by various processes was needed. To accomplish this a computer model was developed which combines three sets of coal data and allows a variety of analyses to be performed on the resultant data base. The model is called the Reserve Processing Assessment Model (RPAM)(10).

The data base is composed of an overlay of the reserve base of U.S. coal, washability data for coal from sample mines, and approximately 50,000 detailed sample coal analyses. All these sets of data were obtained from the U.S. Bureau of Mines in the form of computer tapes. The resulting overlay contains 36,000 coal resource records which have the following information for each:

- Region, state, county, and bed
- Weight in tons of both strip and underground coal
- Mean percent by weight of ash, organic sulfur, and pyritic sulfur
- Mean heat content expressed in Btu/lb
- The float-sink distribution of the coal characteristics.

From this consolidated data base the effect of a coal cleaning process on the reserve resources can be calculated. The coal cleaning process specified can be physical or chemical or real or hypothetical.

Programs were written to perform various analyses on the combined data base. A few of these analyses are described briefly as examples.

(1) Four physical and four chemical coal cleaning processes were defined. The percentage of the coal reserve base that could be made available to meet various fixed SO_2 emission limits by means of each of the processes was calculated for each of six geographic regions. The calculations were performed first with the effect of the variability in the sulfur content ignored, and then for two different emissions-averaging periods and for two different sizes of coal-fired facilities to reflect the effects of sulfur variability. The results were produced in tabular and in graphical form. The results can be used to compare the effectiveness of the several processes when applied to the coals of different regions. Further, the results show the impact on coal availability of various fixed-limit SO_2 emission standards and of various averaging periods for emissions.

(2) The ability of the same eight coal cleaning processes to produce coal to meet standards which require removal of a stated percentage of the sulfur in the raw coal was calculated by region and for various emission-averaging periods to reflect sulfur variability.

(3) Similar calculations were performed for the combined technologies of coal cleaning prior to combustion and flue gas desulfurization (FGD). For the four physical cleaning processes, the fraction of the reserve, by

region, available to meet sulfur removal standards of 90 percent, 85 percent, and 75 percent was calculated as a function of the FGD removal efficiency. The results show, for example, that for 25 percent of the coal in the Northern Appalachian Region, a simple cleaning process consisting of crushing to 1.5 inch top size and separation at 1.6 specific gravity would allow the FGD system to operate at only 75 percent removal efficiency and still meet an 85 percent removal standard. Such a reduction in the requirements placed on the FGD system in actual practice may make the difference between meeting or violating such a standard.

(4) The combined data base was used to estimate the SO_2 reduction which would be achieved if all of the coal produced annually were cleaned before combustion. The cleaning process assumed was 3/8-inch top size separated at 1.3 specific gravity followed by separation of the refuse at 1.6 specific gravity and combination of the 2 float fractions. The calculations were done on a state-by-state basis. The results show that a 32.4 percent reduction in national SO_2 emission could be achieved, at Btu loss in cleaning of only 3.04 percent, if all coal were cleaned by the assumed process.

COAL CLEANING INFORMATION CENTER

The Coal Cleaning Information Center (CCIC) was established to provide an information system of ready access to available and relevant references regarding coal cleaning. During the contract period coal cleaning information was disseminated through the monthly Current Events Summary and the quarterly Coal Cleaning Environmental Review.(51)

The CCIC consisted of a hard-copy file of documents and a computerized data base containing citations of government and industry reports, reports prepared by contractors of EPA, DOE, and other government organizations, conference and symposia proceedings, journal articles, patents, books, and other reference documents. The information content pertains primarily to coal cleaning processes, related environmental and health effects, and applicable pollution control technology.

Storage, search and retrieval functions are facilitated by a computerized data base accessible by remote terminal. The CCIC is capable of providing information support and responses to technical information inquiries for a wide user audience.

A total of approximately 1,400 documents were indexed for input to the CCIC data base over the period of this contract. A user guide for CCIC(50) was prepared as an instruction manual for researchers who are required to make on-line searches of the data base. The CCIC data base provides a major and easily accessible information resource on coal cleaning technology and related environmental topics. Such an information resource is of substantial value in the support of ongoing coal cleaning research.

Two thousand copies of each of the first three issues of the Coal Cleaning Environmental Review(51) were published and disseminated by EPA during the contract period. This publication provided descriptions of current research results and new developments related to coal cleaning processes, related environmental effects, applicable pollution control technology, and a current events summary. Through the Coal Cleaning Environmental Review(51), current information related to coal cleaning was widely disseminated to interested parties in government and industry, thus promoting increased knowledge about and acceptance of coal cleaning as a significant technology for emission control.

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APPENDIX A

LIST OF REPORTS

Reports and Other Documents
Prepared or In Preparation On
U.S. Environmental Protection Agency
Contract No. 68-02-2163
by Battelle's Columbus Laboratories

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